2016

Determining the Value of Birthrank and Parent Age in Thoroughbred Racehorses

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Digital Object Identifier: http://dx.doi.org/10.13023/ETD.2016.245

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DETERMINING THE VALUE OF BIRTHRANK AND PARENT AGE IN THOROUGHBRED RACEHORSES

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
College of Agriculture
at the University of Kentucky

By

Xiurui Cui

Lexington, Kentucky

Director: Dr. C. Jill Stowe, Professor of Agricultural Economics

Lexington, Kentucky

2016

ABSTRACT OF THESIS

DETERMINING THE VALUE OF BIRTHRANK AND PARENT AGE IN THOROUGHBRED RACEHORSE

Thoroughbred racing is referred to as "the sport of Kings", because historically it was a leisure activity of the upper-class. Thoroughbred breeding on the other hand has transformed from a hobby of the upper-class to a worldwide agricultural industry. With the deep involvement of the royal and rich in the Thoroughbred industry, the auction prices of horses are raised significantly at the top end of the market.

Research in the biological sciences suggests there exits correlations between dam age, foal birthrank, and the racing performance of Thoroughbred horses. This study first investigates how the market values these biological factors and whether they are correlated with racehorses' career earnings. We further test the impact of sire age as there is limited literature related to the subject. By using a Hedonic pricing model, results show that Thoroughbred buyers at Keeneland September Sale are willing to pay more for the yearlings at 1st, 2nd, and 3rd birthranks, yearlings out of younger mares age from 4 to 10, and yearlings by experienced sires age from 12 to 18. Results from multivariate regressions suggest negative correlations between foal birthrank, parent age and career earnings.

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KEYWORDS: Hedonic pricing model, Thoroughbred yearling, Buyer risk preferences, Dam's age, Birthrank.

Xiurui Cui

April 27, 2016

DETERMINING THE VALUE OF BIRTHRANK AND PARENT AGE IN THOROUGHBRED RACEHORSES

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ACKNOWLEDGEMENTS

I would like to begin by thanking my advisor, Dr. Jill Stowe for her help and efforts she devoted to my thesis. Dr. Stowe has shared her knowledge and passion for equine economics. Through the beginning to the end of constructing the paper, Dr. Stowe has always been available and willing to advise me with valuable comments and thoughts. I am grateful to have Dr. Stowe as my instructor and mentor.

I would like to acknowledge committee members, Dr. Michael Reed and Dr. Kenneth Burdine, for their valuable comments and encouragement. I also want to thank Charlotte R Hansen, Janis Osborne for helping me revise grammar of my thesis paper, and Hua Zhong, who shared his wisdom in econometrics.

I am also very thankful to his highness Sheikh Mohammed, who granted me the internship opportunity to learn about American Thoroughbred industry. During the one-year program, I found my passion for horses and had the chance to connect with Dr. Stowe.

Additionally, I would like to thank my mother, Jiang Jing and my father, Cui Yun, who have been supportive of my study abroad and encouraging me for the past two years, which have contributed to the successful completion of this thesis research and my master's degree.

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Chapter I: Introduction

Research on the Thoroughbred yearlings (one-year-old horses) market suggests that when buyers make purchasing decisions of Thoroughbred yearlings at public auctions, they rely heavily on numerous sources of information such as pedigree, physical quality, individual characteristics and macro-level attributes. Additionally, decisions are often made based on instinct and experience rather than scientific findings, although this may be changing. This study adds to this field of research by using statistical analysis to provide a more scientific approach to the pricing of Thoroughbreds for buyers and sellers.

I.1. Research Questions and Objectives of the Study

Research in the biological sciences suggests the quality of progeny by Thoroughbred dam (the mother of the horse) decreases over time. This thesis investigates whether these biological factors are taken into account in pricing decisions and whether they are correlated with career performance. More specifically, we investigate whether yearling Thoroughbred buyers consider sire (the father of the horse) age, dam age, and/or foal birthrank in their purchase decisions. Then, we examine whether these same factors are reflected in their racing performance. To test these hypotheses, we first examine the impact of dam age, sire age and foal birthrank on hammer price (the last price called by the auctioneer before the gavel strikes the wood) by utilizing a hedonic pricing model. Then, we use a multivariate regression model with career earnings as the dependent variable to examine whether these factors are correlated with future racing performance.

Then, by computing the marginal values of certain characteristics, we can identify whether the market functions efficiently.

I.2 Thesis Structure

The article proceeds as follows. Chapter 2 provides a brief background of the equine industry, Thoroughbred auctions and the U.S. economy background from 2006-2010. Chapter 3 reviews relevant studies and research. Chapter 4 presents the theoretical model. Chapter 5 presents the empirical model. Chapter 6 describes the data and the descriptive statistics. Chapter 7 presents the results, and Chapter 8 concludes.

Chapter II: Background

II.1. Background of Equine Industry

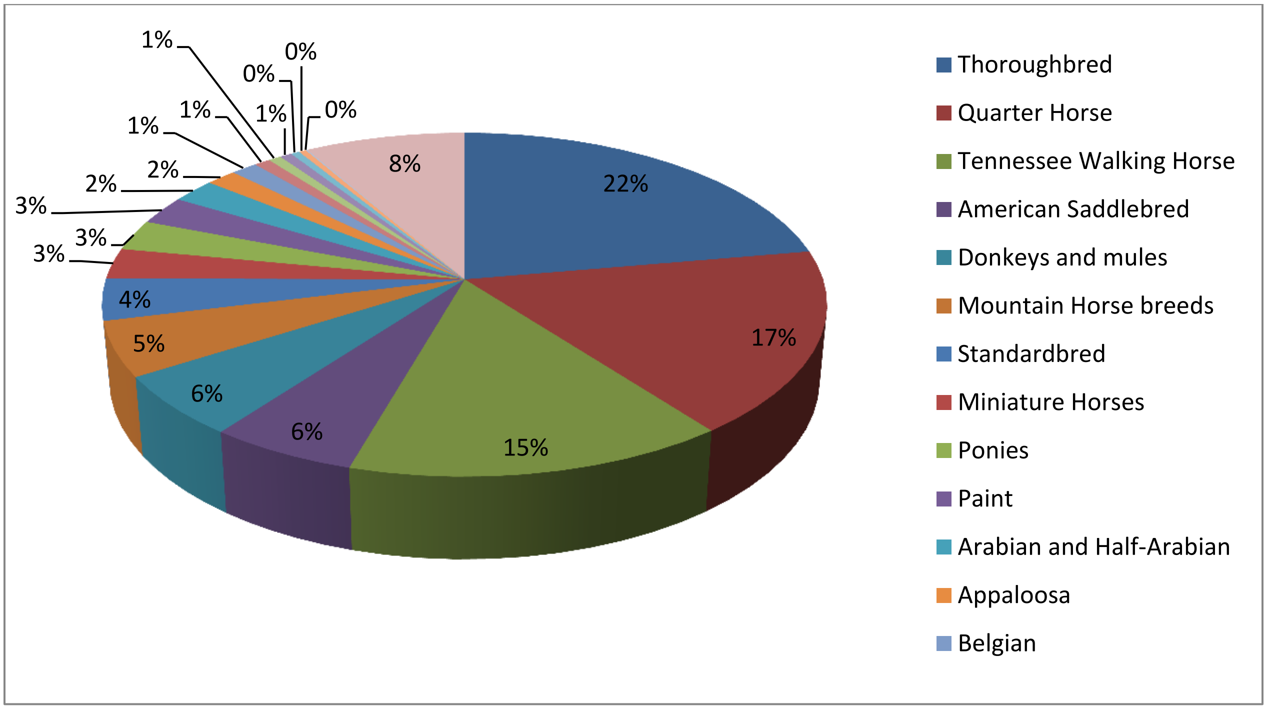
II.1.1. U.S. Equine Industry

The equine industry in the United States has a deep history dating back to settlement of the U.S. and exploration of the west. It is a large and diverse industry which has a significant impact culturally and economically. It spans agricultural, business, sports, gaming and entertainment sectors. A 2005 study conducted by Deloitte Consulting LLP for the American Horse Council Foundation (AHCF)[1] estimated that there were 9.2 million horses in the States. These horses were used for racing, showing, competition, breeding, recreation and work, and the industry was estimated to have a $102 billion impact on the U.S. economy, directly providing 460,000 full-time equivalent jobs and generating $1.9 billion taxes to all level of governments.

II.1.2. Kentucky Equine Industry

Kentucky, the Bluegrass State, is known for its Thoroughbred industry, which plays an important role in providing revenue and jobs to the state. The 2012 Kentucky Equine Survey shows the total of all equine-related sales and income in 2011 was about $1.1 billion, creating 40,665 jobs and contributing $134 million in tax revenues to the state. In addition, the study reports that Kentucky is home to an estimated 242,400 horses, of which Thoroughbreds constitute 24% of the entire inventory, representing the most prevalent breed in Kentucky. Figure 2.1 below shows the percentage of different equine breeds in the state of Kentucky.

Figure 2.1: Kentucky Equine Breeds



II.2. Background of Thoroughbred Industry

II.2.1. National Thoroughbred Racing Industry

Of the total economic impacts, Figure 2.2 and 2.3 suggest the racing industry specifically generates $26.1 billion and creates nearly 384,000 full-time equivalent jobs in the U.S. (Deloitte, 2005) Approximately 560,000 Thoroughbreds are used for racing in the U.S., making up the majority of the racing segment. (Figure 2.4) Thoroughbred racing is shown to be a critical component of the overall equine industry. However, another study conducted by McKinsey & Company for the Jockey Club[2] shows the future of Thoroughbred racing is not promising. The study projects Thoroughbred racing handle will decline 25% in 2020 from 2010, the number of viable tracks will decrease by 27%, and there will be a continuously growing loss of owners. The industry has faced increasing competition with other forms of gambling, sports and entertainment, resulting in a serious decline in number of fans. The study shows the average age of Thoroughbred racing fans is 51 years old, which will increase to 57 by 2020, assuming 2% of the fans die each year.

Figure 2.2: Total Effect on GDP by Breed and Activity in the U.S.

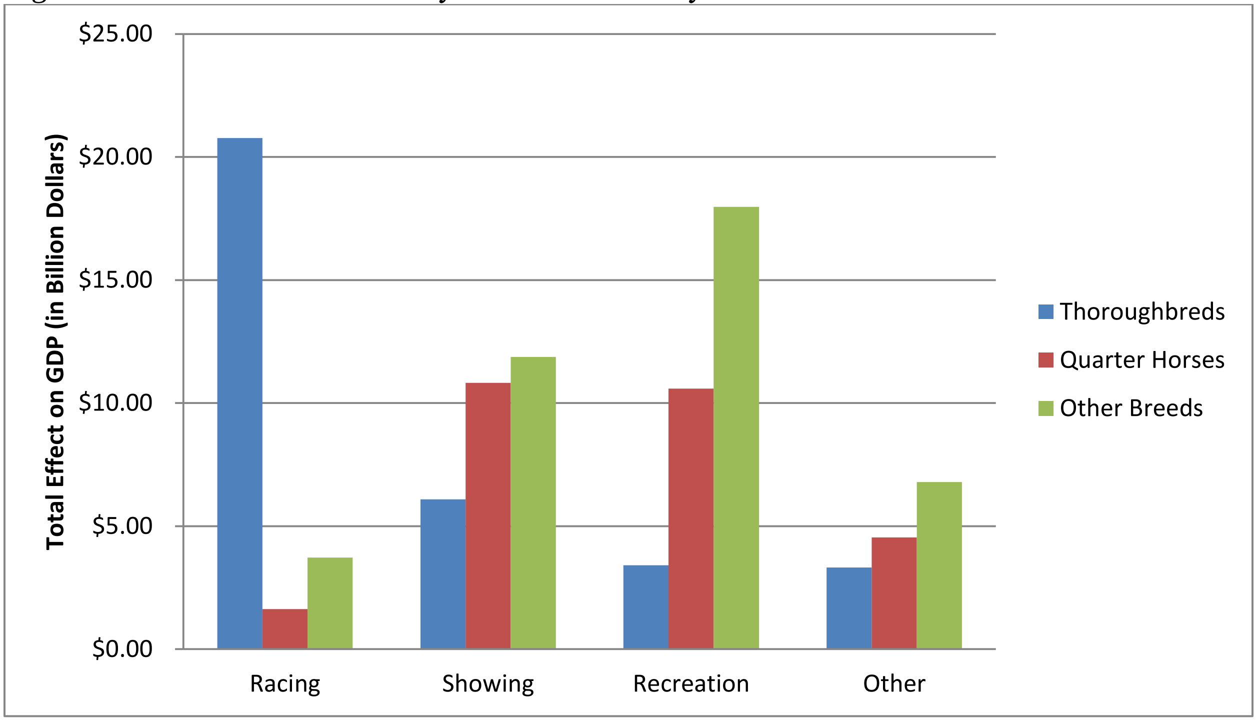


Figure 2.3: Total Effect on Employment by Breed and Activity in the U.S.

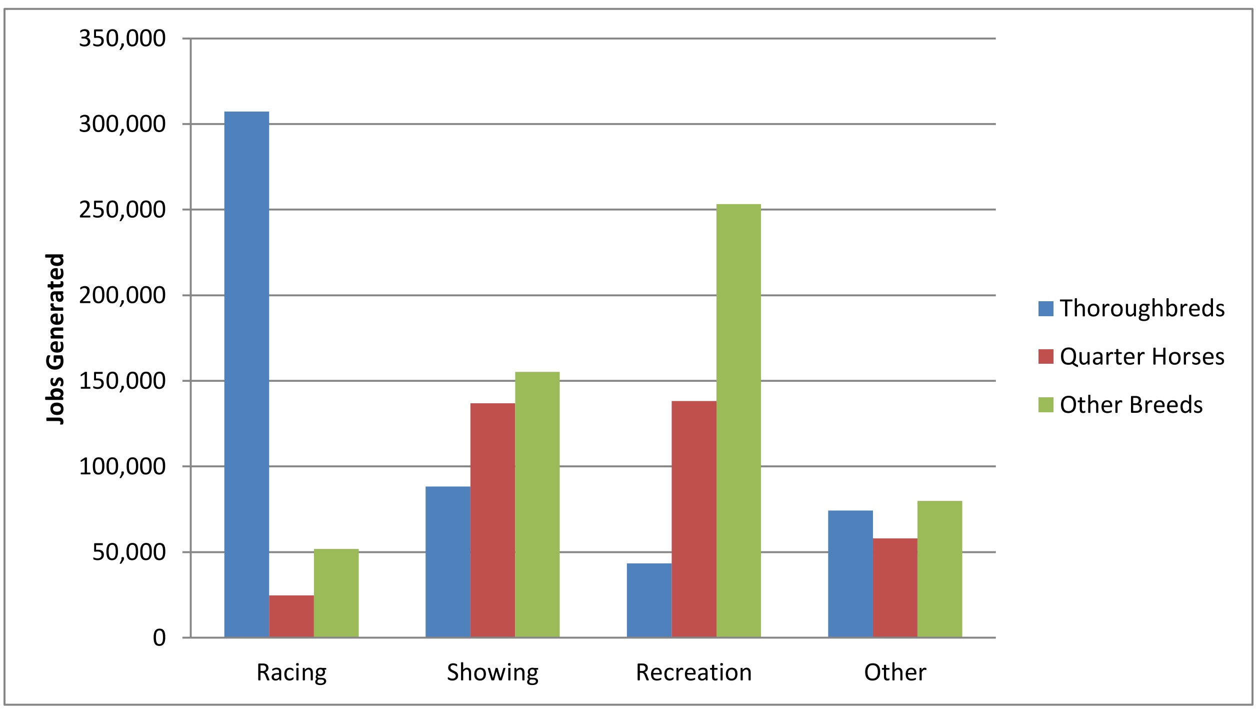
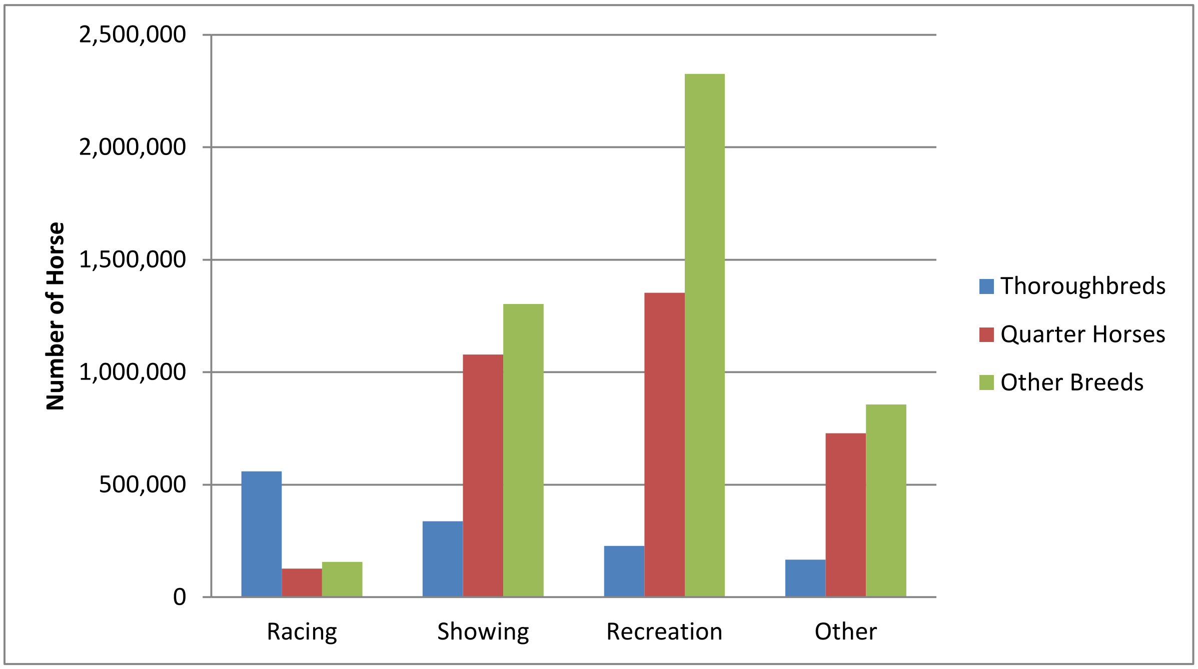


Figure 2.4: Number of Horses by Breed and Activity in the U.S.



Thoroughbred racing is often referred as “the Sport of Kings”, because historically, it was a leisure activity of the upper class. Thoroughbred breeding, on the other hand, has transformed “from a gentleman’s hobby to a global agricultural industry” (Cain 2004). With the involvement of those with deep pockets in the Thoroughbred industry, the prices of Thoroughbred horses in auctions can be quite high, especially at the top end of the market.(Susan, 2013) Evans (2007) shows that more than two-thirds of horse owners in Ontario, Canada, generate most of their annual income from businesses other than equine related activities, and more than 30% have an annual income over $100,000. O’Connor (2011) reports that some who appear on the Forbes Billionaires list are heavily involved in the Thoroughbred industry, including Sheikh Mohammed bin Rashid Al Maktoum (ruler of Dubai and the owner of global Godolphin breeding and racing operation), and

Queen Elizabeth II. Also, a majority of racing and breeding participants come from families with more than 20 years of experience in the Thoroughbred industry.

Recently, animal welfare concerns among various activist groups have had a negative impact on Thoroughbred racing. Thoroughbreds are produced for racing, but one-third never start in a race, and another 20% are not successful. As a result, every year there is an abundance of horses which need new homes; they may be sent back to nature, placed in rescue homes, or even sent to slaughter (although it is illegal to do so)(Mykel, 2013). Groups such as PETA[3] are concerned about the treatment and wellbeing of racehorses, encouraging the public to ban horse racing; this may be contributing to the shrinking of the racing fan base and the decrease of the foal crop each year.

II.2.2. Thoroughbred Breeding Industry

The breeding segment of the industry is largely distinct from racing. Racehorse owners derive their income from competing their horses at racetracks in the form of purses, yet breeders earn their profits from selling horses to buyers either at public auctions or through private transactions. Breeding Thoroughbreds can be as exciting as racing. In 2005, the average price for sold broodmares (mares that produce offspring) at auctions reached $58,235, and the champion filly Ashado sold for $9 million. However, not every Thoroughbred sells for such a high price, and often the hammer price does not even cover the input cost. Despite the odds, there are new breeders who are willing to take the risk to enter the breeding business each year.

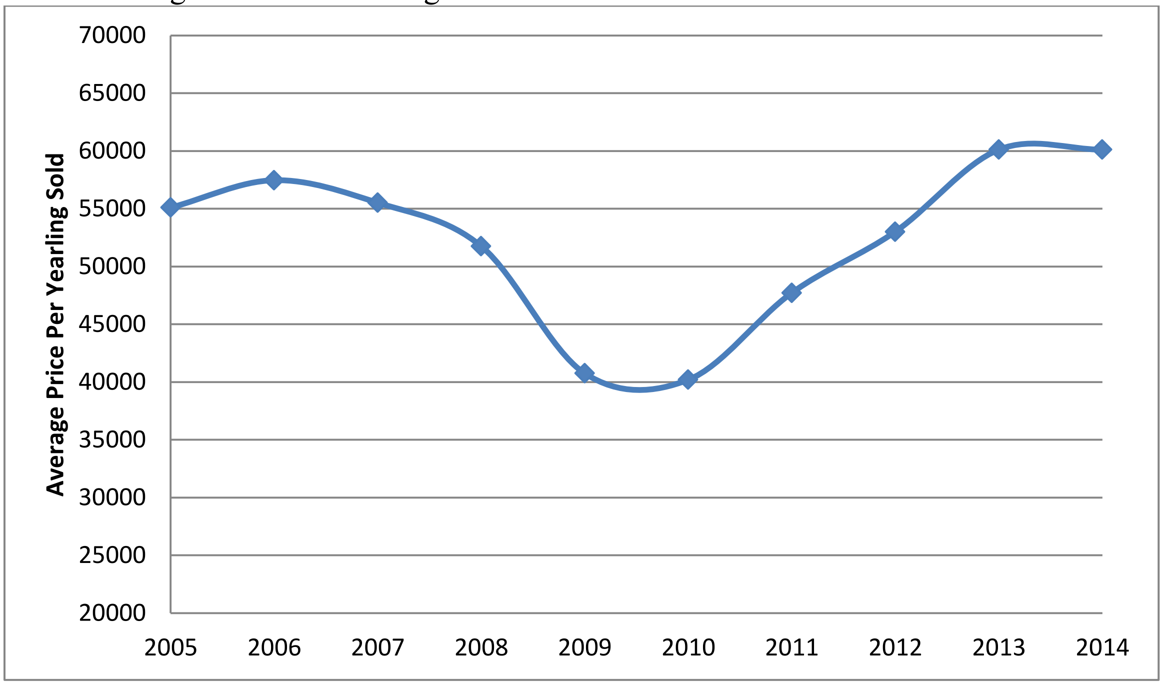
II.2.3. Thoroughbred Auction Industry

Horses and other livestock have been sold at auctions for thousands of years. The first auction house was founded in the middle ages in Europe and flourished during the Renaissance due to the growth of international trade. Auctions are an efficient way to attract a wide range of buyers and sellers, with their clearly established rules and procedures. An ascending auction is the most common way for establishing values for Thoroughbreds. Thoroughbred auctions regularly occur throughout the year. There are yearling auctions, two-year-olds auctions and mixed auctions. Each will be described below.

Yearlings: Yearlings are one-year-old horses. All Thoroughbred horses have a birthday on January 1st each year in the Northern Hemisphere. Most yearlings are prepared to be sold and sent to auctions after mid-July; by that time, they are more developed and look more mature. In addition, buyers prefer to purchase a yearling in fall so they can begin training the next spring or summer. Most sales include horses in all price ranges, with horses with notable pedigrees being sold at the beginning of the sale. Figure 2.5 presents the average price per yearling sold at auctions in North America, and shows a significant decline in 2008 and recovery beginning in 2011.

Fasig-Tipton, which offers yearlings at the Saratoga Sale in New York each August and Kentucky sale in October, has the longest history in the horse auction business; its origins date back to 1898. The Keeneland September Yearling sale in Lexington, Kentucky, is the largest sale of one-year-old Thoroughbreds. Ocala Breeders' Sales[4] in Florida also offers a yearling auction, known as the August Select Sale.

Figure 2.5 Average Price Per Yearling Sold in North America



Two-year-olds in Training: Two-year-olds in Training sales offer two-year-old Thoroughbreds already in race training. These sales are held mainly in late winter and early spring. Such sales offer a quicker return for buyers who may be able to race the horse shortly after purchase. Many of the two-year-olds listed in the sales are 'pinhooks', which means they are purchased as yearlings and resold as two-year-olds with an expectation of profits. Ocala Breeders' Sales in Florida started selling two-year-olds in training in 1957 and is the largest two-year-old sale in the U.S. Other key two-year-old sales include the Fasig-Tipton Florida select sale, the Barretts[5] select sale in California and the Keeneland April two-year-olds in training sale.

Breeding Stock/Mixed: Breeding stock or mixed sales offer not only broodmares, but also horses of racing age, yearlings, weanlings, stallions and broodmare prospects (fillies just off the racetrack). For buyers who invest or have interest in the breeding industry, purchasing a broodmare is one way to start. Weanlings (horses are separated from dam between 6-10 months old, during which period they are referred as ‘weanlings’) are usually sold to buyers with the purpose of reselling them as yearlings to make profits. But even investors with years of experience cannot make profits with every purchase. The leading sale of breeding stock is the Keeneland November sale. Other mixed sales include Fasig-Tipton mixed sales in Kentucky and Maryland in February and December, and Barrett’s and Ocala Breeders’ Sales mixed sales in October.

Information Available at Auctions

Generally, there are three main ways for buyers to learn about the horses at auctions. First, the sales catalog (called the “Book”) is available from the auction house weeks before the actual sale starts so that buyers can learn about each horse. Figure 2.6 shows an example of a catalog page with the following information:

1) the number identifying the horse; called the hip number (also the order they are shown in the sales ring);
2) consignor’s name, followed by the horse’s gender, color and birth date;
3) a 3-generation pedigree of the horse;
4) Highlights of the sire’s racing record and notable progeny;
5) Detailed racing performance and produce record information on the dam side;
6) Bold letters of a horse’s name indicate the horse has earned “Black type”, meaning it has won or placed in a stake race[6].

Buyers also have access to X-rays, radiographs, veterinary reports or voluntary disclosures (announcements of information) in the repository or information center at the auctions. Buyers often seek advice from experts as well, such as bloodstock agents, veterinarians or trainers. Bloodstock agents are people who represent buyers and/or sellers as a business, similar to a real estate agent. They usually have more experience in picking a good quality horse than buyers. Veterinarians play a very important role in the sales, as they help buyers to examine the physical condition of the horses that interested them. Many buyers also prefer to obtain advice from a trainer, as they are more experienced with racehorses and have the ability to identify the horses with desirable physical traits. While some of the information above is ultimately included in empirical models presented in this study, other information is more difficult to measure because it may be subjective in nature or unavailable to the researcher.

Figure 2.6: Sample Catalog Page

Consigned by Hill 'n' Dale Sales Agency, Agent for
Don Alberto Corporation

Barn 7 | **BAY FILLY** | **Hip No. 1**

Foaled April 27, 2014

BAY FILLY	Speightstown	Gone West	Mr. Prospector
			Secrettame
		Silken Cat	Storm Cat
			Silken Doll
	Unappeased (IRE) (2009)	Galileo	Sadler's Wells
			Urban Sea
		Angelic Song	Halo
			Ballade

By SPEIGHTSTOWN (1998). Champion sprinter, black-type winner of $1,258,-256, Breeders' Cup Sprint **[G1]** (LS, $551,200), etc. Among the leading sires, sire of 8 crops of racing age, 727 foals, 551 starters, 69 black-type winners, 439 winners of 1544 races and earning $60,781,629, including champion Essence Hit Man ($1,388,247, Vigil S. **[G3]** (WO, $108,000 (CAN)), etc.), and of Reynaldothewizard **[G1]** ($1,858,290), Golden Ticket **[G1]** ($1,362,590), Haynesfield **[G1]** ($1,319,481), Force the Pass **[G1]**.

1st dam

UNAPPEASED (IRE), by Galileo. Placed at 4, ¥430,000, in Japan. (Total: $5,-465). Dam of 1 registered foal, above.

2nd dam

ANGELIC SONG, by Halo. Unraced. Sister to **GLORIOUS SONG** ($1,004,534, horse of the year in Canada), **DEVIL'S BAG** ($445,860, champion 2-year-old colt), **SAINT BALLADO [G2]**, half-sister to **THAIDAH**. Dam of--

SLIGO BAY (IRE) (c. by Sadler's Wells). Winner at 2, €22,856, in Ireland, 2nd Juddmonte Beresford S. **[G3]**; placed at 2, €18,294, in France, 3rd Criterium de Saint-Cloud **[G1]**, etc.; 3 wins at 3 and 4, $449,060, in N.A./U.S., Hollywood Turf Cup S. **[G1]** (HOL, $150,000), etc. (Total: $484,695). Sire.

LADY BALLADE (IRE) (f. by Unbridled). 7 wins, 2 to 5, ¥166,431,000, in Japan, TCK Jo-o Hai, Queen Sho, 2nd Sparking Lady Cup. (Total: $1,-394,385). Dam of **DANON BALLADE [G2]** (c. by Deep Impact, Total: $3,836,185), **Lord Aries** (c. by Symboli Kris S, 3 wins, Total: $1,162,541).

MILLENNIUM WING (c. by Sadler's Wells). 5 wins, 2 to 5, ¥82,370,000, in Japan, Minami Hokkaido S. (Total: $744,048).

WOLFE TONE (c. by Sadler's Wells). Winner in 2 starts at 2, €21,555, in Ireland, 3rd High Chaparral E.B.F. Mooresbridge S. **[G3]**; winner at 4, £31,990, in England, Paddy Power S. (Total: $84,331). Sire.

Macarena Macarena. Winner at 4, $11,310. Dam of **YUZURU** (f. by Medaglia d'Oro, 2 wins, $99,226, Forever Together S. (DEL, $30,000)).

Angelica Tree. Placed at 3 in Ireland. Producer. Granddam of **Anzan Nistel** (f. by Van Nistelrooy, Total: $29,484, 3rd Alfredo L.S. Jackson **[G3]**, etc.).

Divorce Testimony. Unplaced in 1 start. Dam of **FUSAICHI SEVEN** (c. by Fusaichi Pegasus, Total: $1,699,025, Diolite Kinen, etc.), **Pleasant Divorce** (g. by Pleasant Tap, $156,282, 2nd Gallant Fox H. **[G3]**, etc.).

Fairy Ballade (IRE). Unplaced in 2 starts in Japan. Dam of **Super Moon** (c. by Brian's Time, Total: $1,213,402, 3rd Copa Republica Argentina **[G2]**, etc.), **Grazia** (c. by King Kamehameha, 6 wins, Total: $1,635,419).

Geriba. Producer. Granddam of **Light In Paris** (f. by Aussie Rules, to 3, 2015, Total: $93,723, 3rd Criterium du Fonds Europeen de l'Elevage).

Engagements: E.B.F., Breeders' Cup.

Foaled in Kentucky. (KTDF).

II.3. Keeneland Association

Keeneland Association, Inc., founded in 1936 and located in Lexington, Kentucky, has a deep history and worldwide influence in the Thoroughbred industry, both in racing and breeding. Keeneland began its sale operations in 1943 and has since become the largest Thoroughbred auction house in the world, accounting for about 67% of gross sales in

North America each year. There are four Thoroughbred sales held at Keeneland each year, including a January mixed sale, an April two-year-old in training sale, a September yearling sale and a breeding stock sale in November. A recent economic impact study conducted by the University of Kentucky's Center for Business and Economic Research, Gatton College of Business and Economics, showed that Keeneland's premier spring and fall race meets and four Thoroughbred sales generated a $590 million economic impact for Lexington and Fayette County, Kentucky in 2014. (Christopher 2015)

II.3.1 Keeneland September Yearling Sale

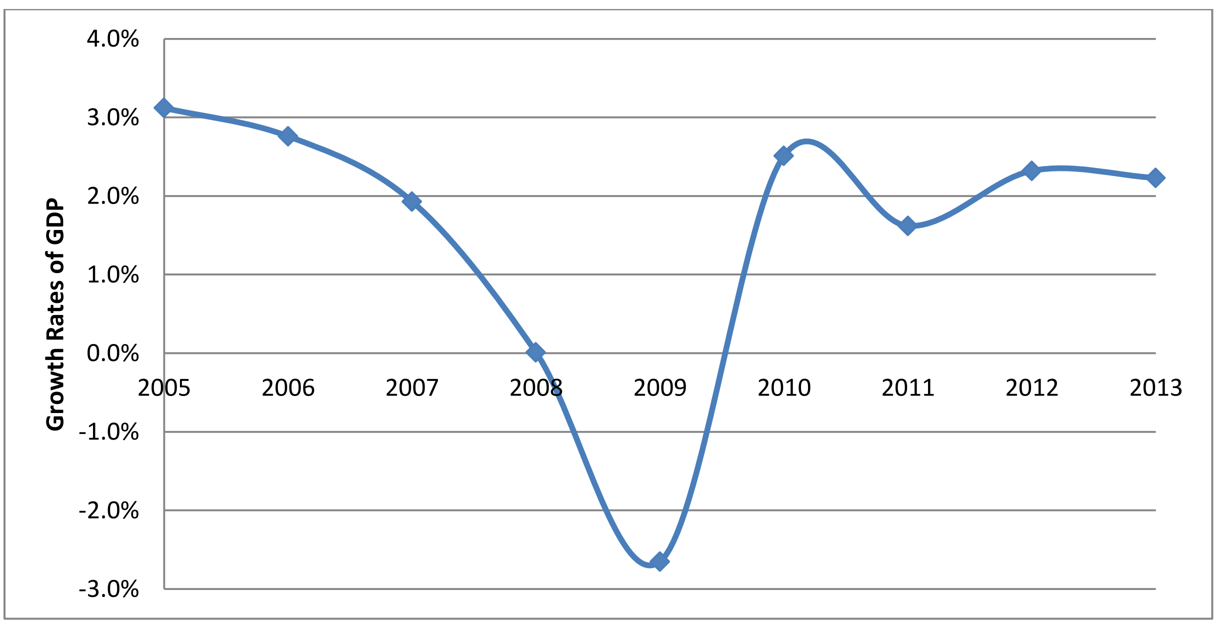
The Keeneland September Yearling Sale is an internationally-known Thoroughbred yearling auction; it is the largest sale of one-year-old Thoroughbreds in the world, which is one of the primary indicators of evaluating the health of the horse industry. Approximately 20% of buyers participating in the September Yearling sales are from outside the U.S., while another 45% are from states other than Kentucky (Christopher, 2015). However, during the economic recession, the total number of yearlings sold decreased and total income decreased significantly. In 2006, 40 horses sold at the auction for more than $1 million, with an average price of $112,427. In 2009, only 4 horses were sold for more than $1 million, and average price was $60,734, a more than 40 percent decrease. At the 2014 September Yearling Sale, 2,819 horses were sold, with an average price of $99,312, and there were 13 yearlings that brought at least $1 million (without adjusting for inflation). Many predicted that even though the industry has appeared to recover from the recession, top horse values would never recover to their 2005-2007 highs.

II.4. The U.S. Economy from 2006-2010

II.4.1. Financial Crisis 2007-08

The financial crisis starting at the end of 2007 is considered to be the worst economic recession in the U.S. since the Great Depression in the 1930s. The bursting of the "housing bubble" triggered the financial crisis, leading to a fall in housing prices, and the meltdown of the subprime mortgage industry. Figure 2.7 shows the rates of growth of real GDP from 2005-2013, which are presented to illustrate the effect of the financial crisis on the U.S. economy. Gross Domestic Product (GDP) growth rates became negative in 2009, suggesting a severe setback of the U.S. market, but started recovering in 2010. The entire world economy was affected significantly, including the equine industry.

Figure 2.7: Rates of Growth of GDP in the U.S.



II.4.2. Economic Recession's Impacts on Thoroughbred Industry

The Thoroughbred industry is an industry competing against other entertainment industries (i.e., casino or other gaming) for a share of gamblers income. When the price of gasoline decreased in recent years, several prominent Thoroughbred owners, such as the owner of Regis Farms sold their property and stock and invested in the gasoline industry. However, the American Thoroughbred industry remains the strongest and deepest compared to the rest of the world. The number of foals produced started decreasing in 2008, featuring a decrease of 12.7% from 2009 to 2010, and 10.3% and 6.2% in the next two years, respectively (Figure 2.8). The foal crop size continues to fall. Although the relationship between this trend and the economic crisis is clear, there are other factors contribute to decreasing production, such as the decrease in the number of races and pari-mutuel wagering[7]. From 1980 to 1989, North America held 463,818 races; in the next decade, there were 375,308 races. This trend continues; there were 368,154 from 2000 to 2009 (Figure 2.9). Demand for racing appears to be decreasing; the number of racing fans is shrinking by almost 20% each year, and hence wagering has decreased. Although the United States is still a major Thoroughbred exporter, the demand for breeding and/or race tracks has decreased continuously (McKinsey, 2011).

Figure 2.8: U.S. Foal Crop

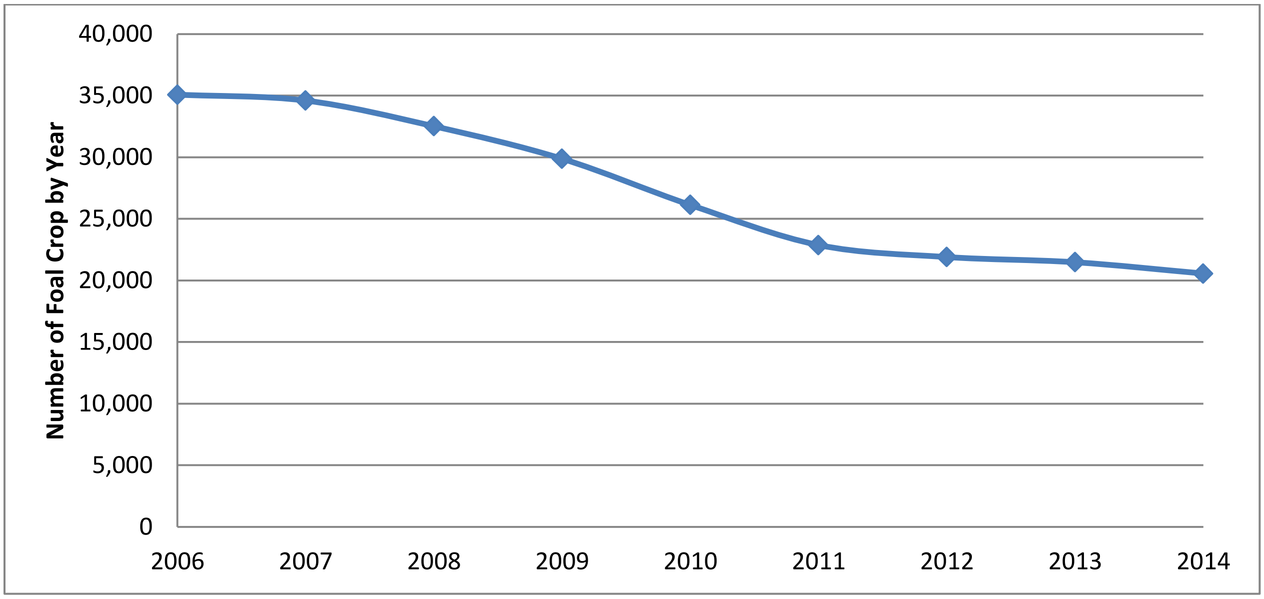
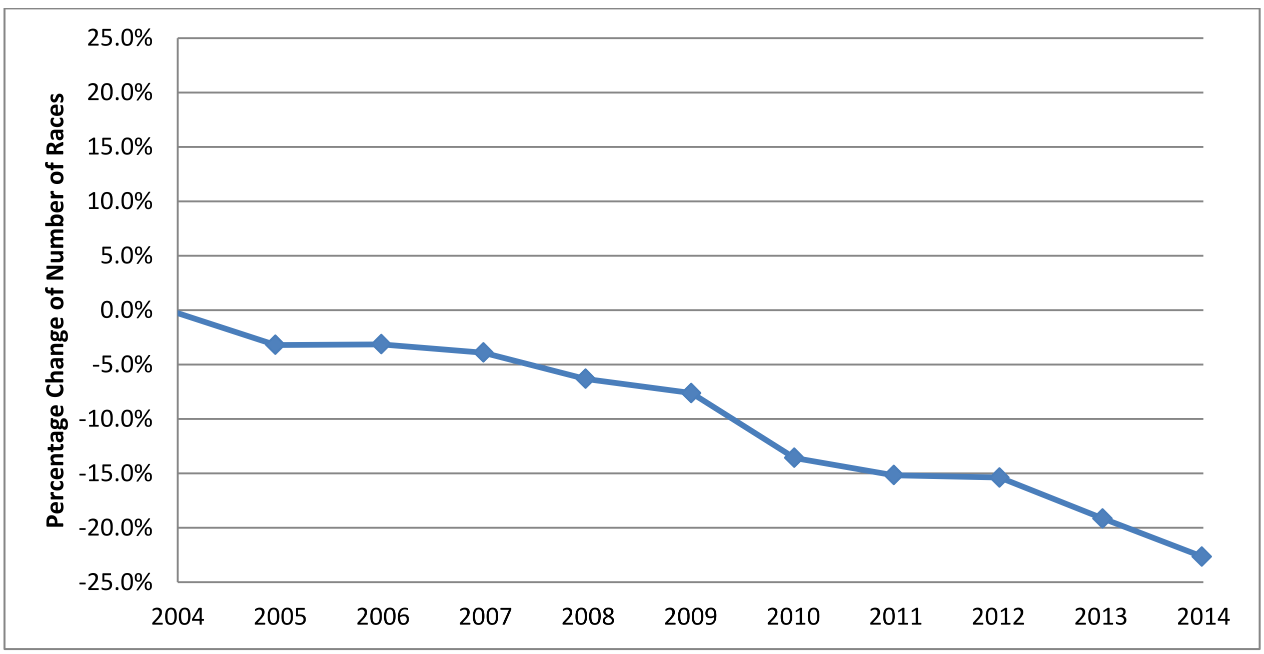


Figure 2.9 Percentage Change of Number of Races in the U.S.



Chapter III: Literature Review

The veterinary science literature has revealed that maternal age influences the bodyweight of their foal and earlier foals (in terms of birthrank) are shown to be more successful in their racing careers than those born at later parities. There is no research on the influence of stallion age that we know of. After reviewing the relevant veterinary science literature, the research on Thoroughbred pricing is summarized.

III.1 Evidence from Veterinary Science Research

Generally, it is considered that the dam of a foal contributes 55-60% of its behavioral and physiological characteristics while the sire is responsible for only 40-45%. The reason is that the maternal influence is non-genetic on the growing fetus and foal, including intrauterine protection and nourishment of her offspring (Hintz 1979; Bhuvanankumar and Satchidanandam 1989).

III.1.1 Impact of Foal Birthrank on Thoroughbred Racing Performance

Finocchio (1986) suggested that a mare's third foal has the best chance to become stakes winners later in life, followed by the 5th, 2nd and 4th foal. In addition, a declining linear relationship was discovered for the incidence of stakes winners after the 5th foal from 15.5% for the sixth foal to 3.7 % for the sixteenth foal. Barron (1995) conducted a statistical study to determine the effect of maternal age and parity (the number of foals previously born) on the racing performance of Thoroughbred horses. In this study, the author randomly selected 100 mares with 8 or more live foals and used Timeform ratings (handicap[8] ratings in pounds, range from 130-145 for top class horses down to 40-50 for inferior racehorses) to represent their racing performance. Results suggested that there was an initial rise to a peak at around the 4th parity that was followed by a consistent decline. The author concluded that foals born at early parities were more successful during their racing careers than those born at later parities.

III.1.2 Impact of Dam Age on Thoroughbred Racing Performance

Hintz (1979) found that progeny from older mares had a lower body weight at birth. Such early influences could affect the performance of the offspring throughout its life. Elsewhere, O'Sullivan (1980) illustrated the progeny of mares less than 16 years old have a higher chance to be successful on the racetracks than those from older mares. Barron (1995) found there was a rise in Timeform ratings of offspring with maternal age, peaking at around 9 years old, followed by a decline. In addition, the data indicated that younger mares produced the most successful offspring in term of Timeform ratings. Our research has an advantage of including a larger data set (22,734 yearlings), and uses lifetime earnings as the rating of their racing quality. With discovering the magnitude of marginal values of each characteristic, we help buyers and sellers of Thoroughbred yearlings to further understand price discovery and provide more statistical information to help them make reasonable and better purchasing decisions.

III.1.3 Impact of Sire Age on Thoroughbred Racing Performance

No previous research has studied the impact of sire age on his progeny in terms of career performance, but this factor is included to investigate any relationship exits.

III.2 Revealed Preferences

Generally, there are two approaches to measure consumers' preferences: revealed preferences and stated preferences. In this paper, we use a revealed preference approach to estimate the marginal values of yearling buyers' willingness-to-pay for different attributes of yearlings, to discover the preferences of Thoroughbred buyers at public Thoroughbred auctions. Willingness-to-pay (WTP) is defined as “the maximum price a buyer will pay for a given quantity of goods or services” (Le Gall-Elly, 2010). A product can be viewed as a combination of quality attributes which consumers choose to maximize their overall utility (Lancaster, 1991). The revealed preference approach is based on the observation of actual actions and choice behavior of the consumers (Ben-Akiva, 1994), and assumes actions of consumers in the market are based on utility maximization. Paul Samuelson first mentioned revealed preference (RP) in 1938, calling it “selected over”. Samuelson states that consumers’ preferences can be revealed using observed market data.

The revealed preference approach is commonly used in measuring demand, which is an essential technique in applied economics. In agricultural economics, revealed preference approach is often applied to food demand. One of the household studies to test demand theory is done by Famulari in 1995. Other studies in the area of food demand include revealing demand for organic and conventional frozen vegetables (Glaser, 1999), and another innovative application of revealed preference approach in auction value (Varian, 2012).

III.3 Determinants of Thoroughbred Yearling Hammer Prices

First, research suggested that the pedigree of the yearling is the most important determinant of hammer price. Controls for pedigree include sire quality and dam quality measures which are to be shown consistently significant (Plant; Stowe, 2013). Stud fee (the fee paid by the mare owner for the right to breed a mare to a stallion) has been shown to be the most efficient way of representing sire quality. Most studies use dam black type as an indicator of the dam racing performance, and use dam progeny black type to denote the quality of the dam produce. Characteristics of individual yearlings such as date of birth, gender and birth are some other significant variables (Parsons, 2008). Vickner (2001) conducted a hedonic hammer price model of yearling sale which also included mare's age as an explanatory variable, but his result showed that mare's age is insignificant to hammer price, which we reach a different conclusion.

The role of voluntary and mandatory disclosures at Thoroughbred auctions can either have a positive or a negative impact (Mathios, 2000). The auction house requires disclosures from Thoroughbred sellers. Mandatory disclosures required by Keeneland include a minimum of 38 x-rays of the horse, a vet statement and specific veterinary scopes and eyes examination (Keeneland Association, Inc., 2014). Because of mandatory disclosure, buyers can be more aware of the physical conditions of the horse in which they are interested in investing (Plant., 2013). On the other hand, mandatory disclosure is shown to be negatively significant on price of the same product. It plays a vital part in the Thoroughbred auction business. Disclosures of surgeries which are designed to make permanent changes in a horse's physical appearance are voluntary. Studies show that the breeders who voluntarily disclose information are the ones who can benefit from it by increasing sales prices. Disclosures of information can be requested and found at the auction.

Commer (2000) suggested that where the yearling was sold, date of sale (yearlings sold at the beginning “select” session of the Keeneland sale are expected of higher quality) were some of the factors affecting Thoroughbred yearling hammer prices. At the Keeneland September Sale, there are usually 7-8 books listing all the yearlings; Book 1-2 normally contain the select ones. Studies show that yearlings sold earlier in placement in the sale generally command a premium (Plant, 2013; Wimmer, 2003). D. Poerwanto, C. J. Stowe (2010) suggested that an increased supply of foals by the same sire at Thoroughbred sales would also influence the average price of yearlings.

Macroeconomic factors such as exchange rates and the interest rate have a significant influence on the Thoroughbred industry. Buzby (1994) found that individual factors were the most significant attributes but tax and interest rates were price determinants as well. The industry is global, and Thoroughbred buyers can choose between auctions in several countries. It is reasonable that the exchange rate between currencies influences international purchases each year.

In conclusion, the characteristics listed above such as pedigree, gender, foaling date, and macroeconomic variables are shown to be significant determinants of yearling prices. However, whether they are also significant determinants of racing performance is unknown.

Chapter IV: Theoretical Model

IV.1 Hedonic Analysis

Hedonic price analysis is a model often used in applied economics to estimate demand or value. The theoretical model is built on work by Lancaster (1991). Hedonic price analysis is useful in estimating the extent to which each characteristic of a good influences the price of that good (Rosen, 1974). It has been developed through two general theories. First, it is based on the consumer behavior theory that a consumer maximizes utility by choosing goods with certain attributes; second, producers view such attributes as inputs in their production function. Both utility and profit maximization view price as a function of attributes associated with the good (Schroeder, Espinosa, Goodman, 1992). Hence, the market equilibrium price represents an array of attributes of the good and represents how market values different attributes of the good. Hedonic price analysis is useful in estimating the marginal value of each explanatory variable and is assumed to follow linear function. A continuous variable which does not follow a normal distribution should be transformed in the model.

Suppose consumers maximize utility, U, given set of different attributes, Z, for a product.

(1) $Max\ U = U\ (Z)$

Given the utility function in (1), the price of the product can be decomposed into a bundle of buyer choices.

(2) $P = f\ (Z_{1,} Z_{2,} \ldots, Zn)$, i=1, …, n

By taking the derivative with respect to each attribute, $\partial P/_{\partial Z_i}$, the value of consumer marginal willingness-to-pay for each attribute of a good can be calculated.

This model is commonly applied in different economic sectors to estimate market demand, including natural resources, the automobile industry and the real estate market. At the beginning of the 20th century, hedonic prices indices were estimated by Court (1939) and Stone (1956), which is a price index describing how product price is explained by its characteristics. It has been applied to calculate price indices for information and communication products and housing (Rosen, 1974).

Hedonic pricing models are also commonly used in studies concerning the Thoroughbred industry. It is used to characterize and analyze the price of Thoroughbreds. With data available, it is possible to identify the determinants of sale price.

Chapter V: Hypotheses and Empirical Model

This chapter presents the empirical approach used to analyze determinants of hammer price and racing performance. It is conducted in two parts. For the former, a log-linear hedonic pricing model is utilized; for the latter, a log-linear multivariate regression is applied to the earnings equation with the same set of explanatory variables. The purpose of this second step is to compare the marginal effects of each independent variable from the two models to determine whether the market efficiently values yearling characteristics. Three regressions are performed for both the hedonic pricing model and the multivariate regression analysis. The first includes only foal birthrank; the second includes only dam age; and finally, both variables are included in the third model.

Marginal effects of the significant attributes are then calculated to compare results from the two model.

V.1 Hedonic Pricing Model in Determining Hammer price

To investigate the relationship between hammer price and yearling characteristics, a log-linear hedonic model is used. The variables price, stud fee and earnings are not normally distributed, so they are transformed using the natural logarithm function. Then, we analyze buyer's marginal willingness to pay for different characteristics of the yearling on its hammer price.

Model (1) specifies the model to be estimated:

$$ln(y_i) = \alpha + x_i\beta + \varepsilon_i,$$

The term y_i is a vector of the yearling hammer price; this auction price is determined in equilibrium by the interaction of buyers and sellers. The term x_i is a matrix of explanatory characteristics that are observed by both the researcher and the consumer, and the mean and variance of the error term ε_i are normally distributed. Several explanatory variables are used in this pricing model, including gender, date of birth of the yearling, the sire stud fee, birthrank of the yearling, performance and dam progeny performance.

V.2 Multiple Regression Analysis to Predict Earnings

Multiple regression or multivariate regression is first mentioned by Pearson (1908); the author identifies as a statistical method to investigate the relationship between multiple independent variables and a dependent variable.

Although there is no theoretical model for predicting Thoroughbred career performance, in this paper, multivariate regression analysis is used to identify the relationship between the yearling attributes and race earnings. There are many ways to measure a racehorse performance on the racetrack, and each has its own advantage and disadvantage. Barron (1995) used handicap weight ratings to represent Thoroughbred racing performance. Other ways to measure racehorse quality include number of wins, average speed, or earnings per start, for example. Chico M.D. (1994) suggested there was a small advantage in using earnings to represent horse racing performance than speed and race ranking. While it is difficult to focus on only one metric to capture the quality of a racehorse, we choose to use racing career earnings.

Similar to the pricing model, we test whether the maternal impact and sire age influence progeny performance.

Model (2) specifies the model to be estimated:

$$ln(y_i) = \alpha + x_i\beta + \varepsilon_i,$$

The term y_i is a vector of yearling's racing earnings up until the year of 2015. The term x_i is a matrix of explanatory variables included in the pricing model. Mean and variance of the error term ε_i are normally distributed. The marginal effects are computed similar to the approach used in the first model.

V.3 Marginal Effects

Marginal effects (measured in dollars) for each significant explanatory variable are calculated. By comparing the marginal values of the independent variables from the two models, we provide evidence of whether characteristics valued by Thoroughbred buyers are significant in explaining earnings of racehorses.

For continuous variables x_i, , the marginal value is estimated as:

$$MV = \beta_i \bar{y}$$

For continuous variables x_i which are transformed using the natural logarithm in the model, the marginal value is estimated as:

$$MV = \beta_i(\bar{y}/_{\bar{x}})$$

For dummy variables x_i, the marginal value is estimated as:

$$MV = exp(\beta_i + \ln(\overline{y_{\iota=0}})) - \overline{y_{\iota=0}}$$

Chapter VI: Data and Descriptive Statistics

In this chapter, the collection of data and variables are described and then summarized using descriptive analysis.

VI.1 Data Collection and Variable Description

VI.1.1 Collection of the Data

Results from the Keeneland September Sale from 2006 to 2010 were obtained from the official Keeneland website. This time span was chosen because by the end of 2015, the horses will be 6-10 years old, and the vast majority will have been retired from racetracks. The sales results provide a collection of information about the listed yearlings, which are available to Thoroughbred buyers at the auction in the format of books. The sequence of the auction books represents the selection preferences of the auction house; Books 1-2 include the “select” yearlings; these individuals have the best pedigrees and conformation. Descriptions of the seller, sire and dam, color, and date of birth of the yearling sold are provided in the summaries. The advertised stud fee at the time of breeding of each stallion is obtained from 2011 *American Produce Records*, which contains detailed race and auction records and pedigrees of all registered Thoroughbred horses since 1960. Dam performance on the racetrack and dam progeny performance statistics are also retrieved from 2011 *American Produce Records*. Several missing advertised stud fees were obtained from *Blood-Horse Stallion Registry*, which collects information of all registered stallions on the market. Nevertheless, the *Blood-Horse Stallion Registry* only contains the information for Thoroughbred registered in United States. For European sires which have listed offspring at Keeneland, stud fees are obtained from the *Racing Post*, and then converted into U.S. dollars using exchange rates at the time of the auction. The *Racing Post* is a European-based company featuring information in the Thoroughbred industry. Race earnings of each yearling by the year of 2015 are obtained from *Equineline Mare Produce Records*. Horses which never started raced are excluded from the entire statistical analysis. Horses with zero lifetime earnings but a winning record are also excluded because such horses may have been competing in other countries yet not recorded by *Equineline Mare Produce Records*.

VI.1.2 Variables Description

The set of characteristics we include in the study is available to the buyer, and previous research has shown that characteristics are often influential when selecting prospective racehorses at auctions (Listed in Chapter 3).

Yearling's Characteristics

Individual yearling characteristics include age and gender, DOB (birth date of the yearling), takes the value of one if the yearling was born between January 1^{st} and April 1^{st} of the year, which is considered to be an early foal in the Thoroughbred industry. Early born yearlings are usually bigger in size and more mature physically by September than late-born yearlings. There are three categories for gender of horses: colt, filly and gelding. A colt is an intact male horse (COLT), a filly is a female horse (FILLY), and a gelding is a castrated male. There are only six geldings in the entire data set, so they are excluded from the study. KY denotes whether the yearling is Kentucky-bred or not; evidence from prior studies is mixed regarding both the sign and significance of this variable. EARN takes the value of their career earnings by the year 2015. By this time, nearly all yearlings in the study are likely retired, so that earnings can be used to represent incomes of their entire racing career.

Pedigree-Sire & Dam Characteristics

The variable STUDFEE is used to represent sire quality; a higher stud fee indicates a more successful producing history and a sire in higher demand. STUDFEE is expected to be a positive and significant determinant of sales prices. In the model, the natural log transformation of STUDFEE, ln (STUDFEE) is used to normalize the distribution. Variables related to dam quality include DAMBT and DAMPROBT. DAMBT is equal to one if the yearling's dam placed in a stakes race. DAMPROBT is equal to one if any progeny of the dam has won or placed in a stakes race and thereby earned black type. DAM_AGE indicates the age of each mare at the time of each auction; it is predicted that this variable is negatively related to price. The variable CROP indicates the birthrank of the yearling. SIRE_AGE represents the age of the sire by the time of breeding.

Other Observed Attributes

PRICE represents the hammer price for each yearling. In the model, the natural log of PRICE, ln (PRICE) is used to normalize the distribution. RNA is a dummy variable equal to one if the hammer price of the yearling did not meet its seller's reserve price. BOOK (1-8) is a set of dummy variables indicating in which book the yearling was listed.

Names and the definitions of the variables are presented in Table 6.1.

Table 6.1: Definitions of Variables

Variable	Definition of Variable
PRICE	Final hammer price.
EARN	Race earnings of each horse by 2015.
BOOK (1-8)	A set of dummy variables indicating in which book the yearling was sold.
DOB	=1 if yearling is born between January 1^{st} and April 1^{st}.
COLT	= 1 if yearling is a male horse.

Table 6.1(continued): Definitions of Variables

Variable	Definition of Variable
FILLY	= 1 if yearling is a female horse.
RNA	= 1 if a yearling does not meet the reserve price set by the seller.
DAM_AGE	The age of each dam at the present auction.
SIRE_AGE	The age of each sire at the present auction.
CROP	The birthrank of the yearling.
STUDFEE	Advertised price of one breeding season to the sire at the time of breeding.
DAMPROBT	= 1 if progeny produced by yearling's dam stakes-placed.
DAMBT	= 1 if yearling's dam is stakes-placed.

Given these variables, the specific form of the pricing model to be estimated is written as:

Model 1a: Include CROP.

$$\begin{aligned} ln(PRICE_i) = {} & \beta_0 + \beta_1 BOOK2_i + \cdots + \beta_7 BOOK8_i + \beta_8 DOB_i + \beta_9 FILLY_i + \beta_{10} RNA_i \\ & + \beta_{11} ln(STUDFEE_i) + \beta_{12} DAMPROBT_i + \beta_{13} DAMBT_i + \beta_{14} CROP_i \\ & + \beta_{15} SIRE\_AGE_i + \beta_{16} YEAR2007_i + \cdots + \beta_{19} YEAR2010_i + \varepsilon_i \end{aligned}$$

Model 1b: Include DAM_AGE

$$
\begin{aligned}
ln(PRICE_i) = \beta_0 &+ \beta_1 BOOK2_i + \cdots + \beta_7 BOOK8_i + \beta_8 DOB_i + \beta_9 FILLY_i + \beta_{10} RNA_i \\
&+ \beta_{11} ln(STUDFEE_i) + \beta_{12} DAMPROBT_i + \beta_{13} DAMBT_i \\
&+ \beta_{14} DAM\_AGE_i + \beta_{15} SIRE\_AGE_i + \beta_{16} YEAR2007_i + \cdots \\
&+ \beta_{19} YEAR2010_i + \varepsilon_i
\end{aligned}
$$

Model 1c: Include both CROP and DAM_AGE

$$
\begin{aligned}
ln(PRICE_i) = \beta_0 &+ \beta_1 BOOK2_i + \cdots + \beta_7 BOOK8_i + \beta_8 DOB_i + \beta_9 FILLY_i + \beta_{10} RNA_i \\
&+ \beta_{11} ln(STUDFEE_i) + \beta_{12} DAMPROBT_i + \beta_{13} DAMBT_i + \beta_{14} CROP_i \\
&+ \beta_{15} DAM\_AGE_i + \beta_{16} SIRE\_AGE_i + \beta_{17} YEAR2007_i + \cdots \\
&+ \beta_{20} YEAR2010_i + \varepsilon_i
\end{aligned}
$$

The specific form of the multivariate regression model to be estimated is written as:

Model 2a: Include CROP.

$$
\begin{aligned}
ln(EARN_i) = \beta_0 &+ \beta_1 BOOK2_i + \cdots + \beta_7 BOOK8_i + \beta_8 DOB_i + \beta_9 FILLY_i + \beta_{10} RNA_i \\
&+ \beta_{11} ln(STUDFEE_i) + \beta_{12} DAMPROBT_i + \beta_{13} DAMBT_i + \beta_{14} CROP_i \\
&+ \beta_{15} SIRE_{AGE_i} + \beta_{16} YEAR2007_i + \cdots + \beta_{19} YEAR2010_i \\
&+ \beta_{20} \ln(PRICE_i) + \varepsilon_i
\end{aligned}
$$

Model 2b: Include DAM_AGE

$$
\begin{aligned}
ln(EARN_i) = \beta_0 &+ \beta_1 BOOK2_i + \cdots + \beta_7 BOOK8_i + \beta_8 DOB_i + \beta_9 FILLY_i + \beta_{10} RNA_i \\
&+ \beta_{11} ln(STUDFEE_i) + \beta_{12} DAMPROBT_i + \beta_{13} DAMBT_i + \beta_{14} DAM_{AGE_i} \\
&+ \beta_{15} SIRE_{AGE_i} + \beta_{16} YEAR2007_i + \cdots + \beta_{19} YEAR2010_i \\
&+ \beta_{20} \ln(PRICE_i) + \varepsilon_i
\end{aligned}
$$

Model 2c: Include both CROP and DAM_AGE

$$
\begin{aligned}
ln(EARN_i) = \beta_0 &+ \beta_1 BOOK2_i + \cdots + \beta_7 BOOK8_i + \beta_8 DOB_i + \beta_9 FILLY_i + \beta_{10} RNA_i \\
&+ \beta_{11} ln(STUDFEE_i) + \beta_{12} DAMPROBT_i + \beta_{13} DAMBT_i + \beta_{14} CROP_i \\
&+ \beta_{15} DAMA_{GE_i} + \beta_{16} SIRE_{AGE_i} + \beta_{17} YEAR2007_i + \cdots \\
&+ \beta_{20} YEAR2010_i + \beta_{21} \ln(PRICE_i) + \varepsilon_i
\end{aligned}
$$

VI.2 Descriptive Statistics

A descriptive analysis is used to compare differences in means of variables. First, means of hammer price of yearlings sold at Keeneland September Sale from 2006 to 2010 are calculated. Since the present study is focused on relationships between parent age and the birthrank with hammer prices and career earnings, the means of price and race earnings of yearlings are calculated and divided into different groups based on dam age and birthrank. Comparing means of price and earnings of yearlings in groups provides a general idea of the average payoff of investing in a racing horse on average. Table 6.2 shows the total number of yearlings, average price, and average career earnings according to different classifications discussed previously.

Table 6.2: Sample Descriptive Statistics

Classification	Total No. of Yearlings	Average Price	Average Earnings
By Year			
2006	4,548	$100,876	$38,746
2007	4,885	$94,064	$58,456
2008	4,787	$84,901	$56,105
2009	4,354	$58,106	$58,677
2010	4,166	$59,779	$65,593
By Gender			
Colt	11,884	$90,889	$64,711
Filly	10,856	$70,031	$45,142
By Date of Birth			
Born before April 1st	13,043	$88,143	$56,246
Born After April 1st	9,697	$71,231	$54,189
By Dam Age			
Dam Age 4-10	11,875	$80,510	$80,510
Dam Age 11-15	7,127	$80,717	$54,940
Dam Age >15	3,738	$82,680	$44,477
By Birthrank			
Birthrank<=5	14,707	$79,310	$58,971
Birthrank 6-10	6,389	$83,558	$50,100
Birthrank >10	1,089	$74,021	$42,575
By Sire Age			
Sire Age 5-10	11,820	$61,883	$66,190
Sire Age 11-15	7,285	$84,464	$68,081
Sire Age >15	3,629	$136,011	$60,337

Table 6.3 presents the distribution of black-type horses and winners by birthrank. We include 22,734 yearlings in this study, of which 9.69% are black-type horses. Of the 2,203 black-types horses, the 3rd crop has the highest chance of becoming black-type horses, 11.43%, followed by 2nd crop (11.12%), 5th (10.58%) and 4th (10.28%). This supports the study by Finocchio (1986) that 3rd crop foals have the highest chance of being stakes winners. The entire data shows 63.51% of the sold yearlings have won at

least one race by 2015; the 2nd crop has the highest percentage of winners, 67.53%, followed by 3rd crop (65.37%), 4th (64.80%) and 5th(64.64%).

Table 6.3: Distribution of Black-type Horses and Winners by Birthrank

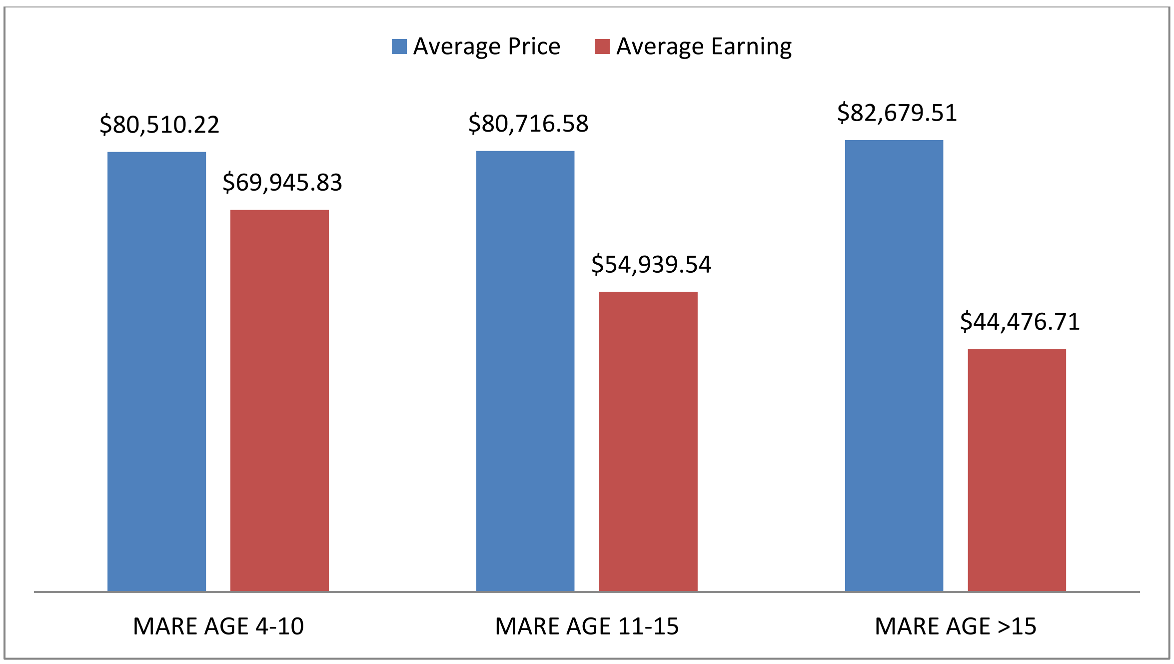
Birthrank	No. of Black-type Horses	No. of Winners	Total No. of Foals	BT%	Win%
Crop 1	297	2296	3613	8.22%	63.55%
Crop 2	357	2167	3209	11.12%	67.53%
Crop 3	355	2031	3107	11.43%	65.37%
Crop 4	268	1690	2608	10.28%	64.80%
Crop 5	231	1411	2183	10.58%	64.64%
Crop 6	167	1168	1812	9.22%	64.46%
Crop 7	149	976	1567	9.51%	62.28%
Crop 8	130	785	1254	10.37%	62.60%
Crop 9	79	572	942	8.39%	60.72%
Crop 10	54	456	806	6.70%	56.58%

Table 6.3 (continued): Distribution of Black-type Horses and Winners by Birthrank

Birthrank	No. of Black-type Horses	No. of Winners	Total No. of Foals	BT%	Win%
Crop 11	35	299	554	6.32%	53.97%
Crop 12	35	241	413	8.47%	58.35%
Crop 13	21	143	274	7.66%	52.19%
Crop 14	12	95	163	7.36%	58.28%
Crop 15	10	54	115	8.70%	46.96%
Crop 16	2	27	53	3.77%	50.94%
Crop 17	0	16	40	0.00%	40.00%
Crop 18	0	9	17	0.00%	52.94%
Crop 19	1	1	5	20.00%	20.00%
Crop 20	0	0	4	0.00%	0.00%
Crop 21	0	1	1	0.00%	100.00%
Total	2,203	14,438	22,734	9.69%	63.51%

More than 50% of the yearlings offered at the sale are out of younger mares (age 4-10 years old) for the following reasons. First, anecdotally, Thoroughbred breeders believe yearling buyers prefer progeny produced by younger mares. Second, aged mares without any known progeny, or who also have a lower productivity, usually stop breeding as breeders cannot earn a profit by breeding them. Figure 6.1 shows the comparison of yearlings average hammer prices and racing earnings by dam age group. It is observed that the average price of progeny by mare age group is nearly identical, whereas there is a decrease in the average career earnings of progeny.

Figure 6.1: Comparison of Sample Average Price and Average Earnings by Dam Age



Chapter VII: Results

This chapter presents the results. First, results from the hedonic pricing model are presented; then, results from the multivariate regressions are presented. Finally, we compare the marginal effects of each significant attribute from the two models.

VII.1 Goodness-of-Fit

Both the Hedonic pricing model and multivariate regression are estimated by ordinary least squares (OLS). After conducting the Ramsey RESET test, we find out there exists cubic relationships between CROP, DAM_AGE, SIRE_AGE, and yearling hammer price in the model, which is the best fit for estimating yearling hammer prices. Since three regressions are performed for both the hedonic pricing model and the multivariate regression analysis, the adjusted R^2 is used to compare goodness-of-fit among three regressions. The adjusted R^2s for the hedonic pricing regressions are: 0.5275 (only include CROP), 0.5270 (only include DAM_AGE), and 0.5274 (include both CROP and DAM_AGE). The model that only includes CROP is the best fit. For the multivariate regressions, the adjusted R^2 are: 0.0484 (only include CROP), 0.0483 (only include DAM_AGE), and 0.0484 (include both CROP and DAM_AGE). The low adjusted R^2s from the multivariate regressions illustrate that it is much more difficult to predict an future racehorses's performance.

VII.2 Results of Hedonic Pricing Model

Results of the hedonic pricing model are presented in Table 7.1.

Table 7.1: Results of the Hedonic Pricing Model

	Model 1a	Model 1b	Model 1c
Dependent Variable	LNPRICE	LNPRICE	LNPRICE
Variables Name	Parameter Estimate (Std Error)	Parameter Estimate (Std Error)	Parameter Estimate (Std Error)
Book2	-0.6473*** (0.0333)	-0.6469*** (0.0333)	-0.6473*** (0.0333)
Book3	-1.1149*** (0.0353)	-1.1150*** (0.0353)	-1.1149*** (0.0353)
Book4	-1.6875*** (0.0366)	-1.6888*** (0.0366)	-1.6874*** (0.0366)
Book5	-2.1127*** (0.0388)	-2.1127*** (0.0389)	-2.1125*** (0.0388)
Book6	-2.7505*** (0.0406)	-2.7523*** (0.0406)	-2.7503*** (0.0406)
Book7	-3.1539*** (0.0436)	-3.1555*** (0.0437)	-3.1536*** (0.0437)
Book8	-3.5137*** (0.0536)	-3.5138*** (0.0537)	-3.5132*** (0.0537)
DOB	0.0930*** (0.0155)	0.0938*** (0.0154)	0.0934*** (0.0156)
Filly	-0.1028*** (0.0151)	-0.1025*** (0.0151)	-0.1028*** (0.0151)
RNA	-0.3163*** (0.0175)	-0.3166*** (0.0175)	-0.3162*** (0.0175)
lnStudfee	0.1671*** (0.0115)	0.1645*** (0.0115)	0.1668*** (0.0115)
DAMPROBT	0.3000*** (0.0215)	0.2873*** (0.0210)	0.3004*** (0.0215)
DAMBT	0.1066*** (0.0165)	0.1204*** (0.0168)	0.1080*** (0.0173)
CROP	0.0397*** (0.0165)	-	0.0412** (0.0175)
CROP ^{2}	-0.0085*** (0.0025)	-	-0.0085*** (0.0025)
CROP ^{3}	0.0003*** (0.0001)	-	0.0003*** (0.0001)
DAM_AGE	-	0.1167*** (0.0345)	-0.0014 (0.0052)

Table 7.1 (continued): Results of the Hedonic Pricing Model

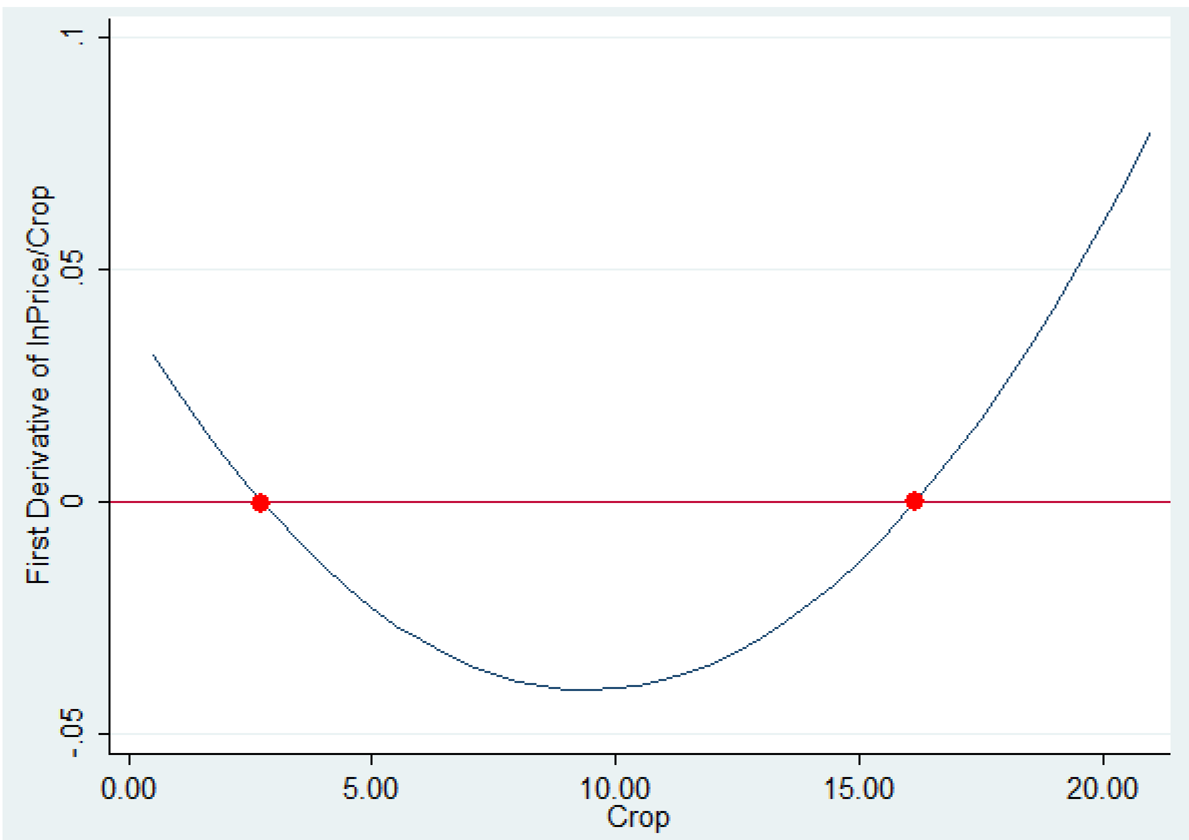
	Model 1a	Model 1b	Model 1c
Dependent Variable	LNPRICE	LNPRICE	LNPRICE
Variables Name	Parameter Estimate (Std Error)	Parameter Estimate (Std Error)	Parameter Estimate (Std Error)
DAM_AGE^2	-	-0.0089*** (0.0027)	-
DAM_AGE^3	-	0.0002*** (0.0001)	-
SIRE_AGE	-0.2159*** (0.0304)	-0.2140*** (0.0304)	-0.2159*** (0.0304)
$SIRE\_AGE^2$	0.0167*** (0.0021)	0.0166*** (0.0021)	0.0167*** (0.0021)
$SIRE\_AGE^3$	-0.0004*** (0.0000)	-0.0004*** (0.0000)	-0.0004*** (0.0000)
YEAR2007	0.1761*** (0.0238)	0.1871*** (0.0238)	0.1768*** (0.0240)
YEAR2008	-0.0949*** (0.0239)	-0.0840*** (0.0239)	-0.0943*** (0.0241)
YEAR2009	-0.6271*** (0.0241)	-0.6158*** (0.0240)	-0.6265*** (0.0242)
YEAR2010	-0.8726*** (0.0247)	-0.8619*** (0.0246)	-0.8719*** (0.0248)
Intercept	11.2931*** (0.1849)	11.4575*** (0.1849)	11.3022*** (0.1879)
N	22734	22734	22734
Missing Values	0	0	0
Adjusted R^2	0.5275	0.5270	0.5274
F Value	1104.29	1207.35	1058.24
Prob > F	<.0001	<.0001	<.0001
Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.			

VII.2.1 Results of Hedonic Pricing Model with Including CROP

First, the results from Model (1a) are presented. Our variable of interest is CROP, which ranges from 1 to 21. After performing a RESET test, a cubic correlation between CROP and lnPrice shows that this is the best model. Figure 7.1 illustrates the non-linear relationship, which can be interpreted as there being a positive correlation between 1^{st}-3^{rd}

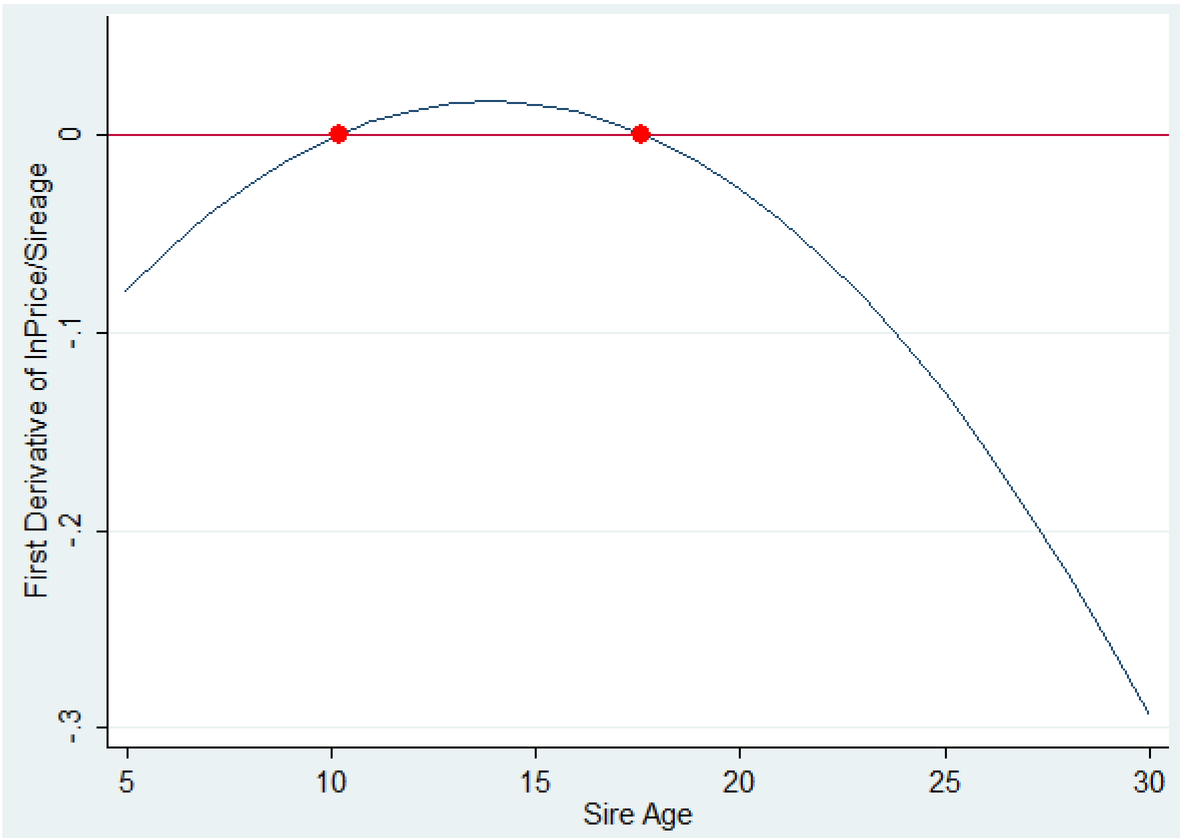
crop and hammer price, with price of the 3rd crop higher than the other crops. Price starts to decrease from the 4th crop, but then shows an increasing positive relationship from the 17th crop. This might be a small number result, since only 0.29% of the yearlings included in the study have a birthrank greater than 17. This result provides empirical support for the anecdotal evidence that yearling buyers believe the first three crops of foals are supposed to be the progeny with highest qualities.

Figure 10: First Derivative of lnPrice with respect to Crop



In addition, the variable SIRE_AGE, which ranges from 5 to 30 years old, also fits best with a cubic correlation function according to a RESET test. Figure 7.2 shows there is a pattern: there is a negative correlation between yearling hammer price and sire age at 5 years, then it turns positive from age 12 to 18, until it begins decreasing again.

Figure 11: First Derivative of lnPrice with respect to SIRE_AGE



Most of the attributes of price identified in previous studies are shown to be significant with the expected signs. First, the coefficients of BOOK (2-8) are all negative and significant at the 1% level, indicating a negative correlation between prices and increasing book numbers as compared to Book 1. The coefficient for DOB is positive and significant at the 1% level; early born yearlings are more physically mature than yearlings born after April 1st, and buyers prefer more developed yearlings. The signs of

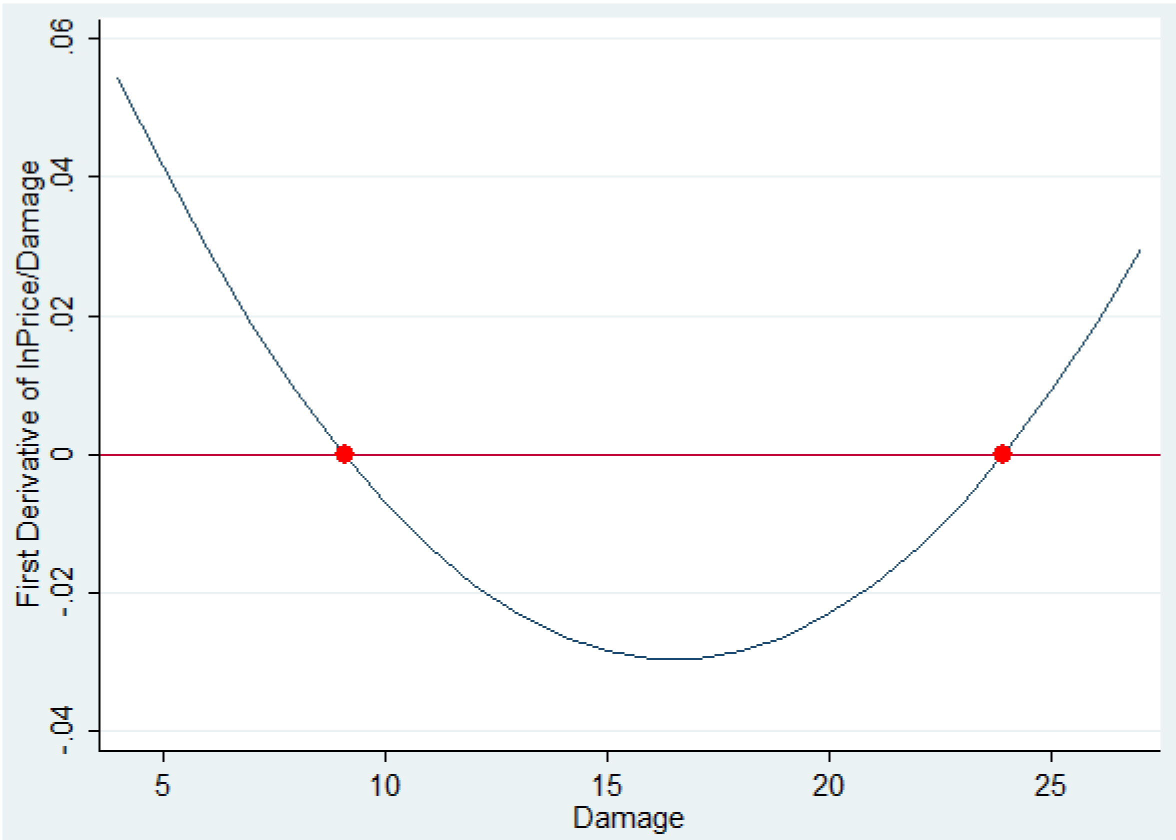
FILLY and RNA are both negative and significant at the 1% level, indicating yearling buyers prefer colts rather than fillies. The negative coefficient on RNA can be interpreted as a proxy for information that is unobservable to the researcher but not to the buyer/seller, resulting in the reserve price not being met. The variables controlling for sire, dam quality, lnStudfee, DAMBT and DAMPROBT, are all positive and significant at the 1% level as expected. The coefficients for YEAR2007 is positive and significant at the 1% level, suggesting higher average prices than in 2006. The coefficients for YEAR2008, YEAR2009 and YEAR2010 are negative and significant at the 1% level, which is not surprising given the effect of the U.S. economy downturn in 2008.

VII.2.2 Results of Hedonic Pricing Model with Including DAM_AGE

Second, the results for Model 1b are presented. This model utilizes dam age rather than foal birthrank. All attributes are significant at the 1% level (Table 7.1). The results for the attributes other than dam age are robust to the change in specification. Again, a cubic relationship between sire age and hammer price exists, and the results are nearly identical to those in Model 1a.

The RESET test suggests a cubic pattern for the effect of DAM_AGE on price, and DAM_AGE ranges from 4 to 27. Figure 7.3 illustrates the non-linear relationship. Price is increasing in dam age for 4 to 10, with average hammer prices for yearlings out of 10-year-old mares reaching the maximum. Then, price begins decreasing when the dam reaches 11 years old and continues until the age of 25. One possible explanation for this result is that the number of yearlings out of mares age from 25 to 27 are a relatively small portion of the entire sample. Another possible explanation might be that mares are still producing at that age because they have produced high quality foals more consistently.

Figure 12: First Derivative of lnPrice with respect to Dam_Age

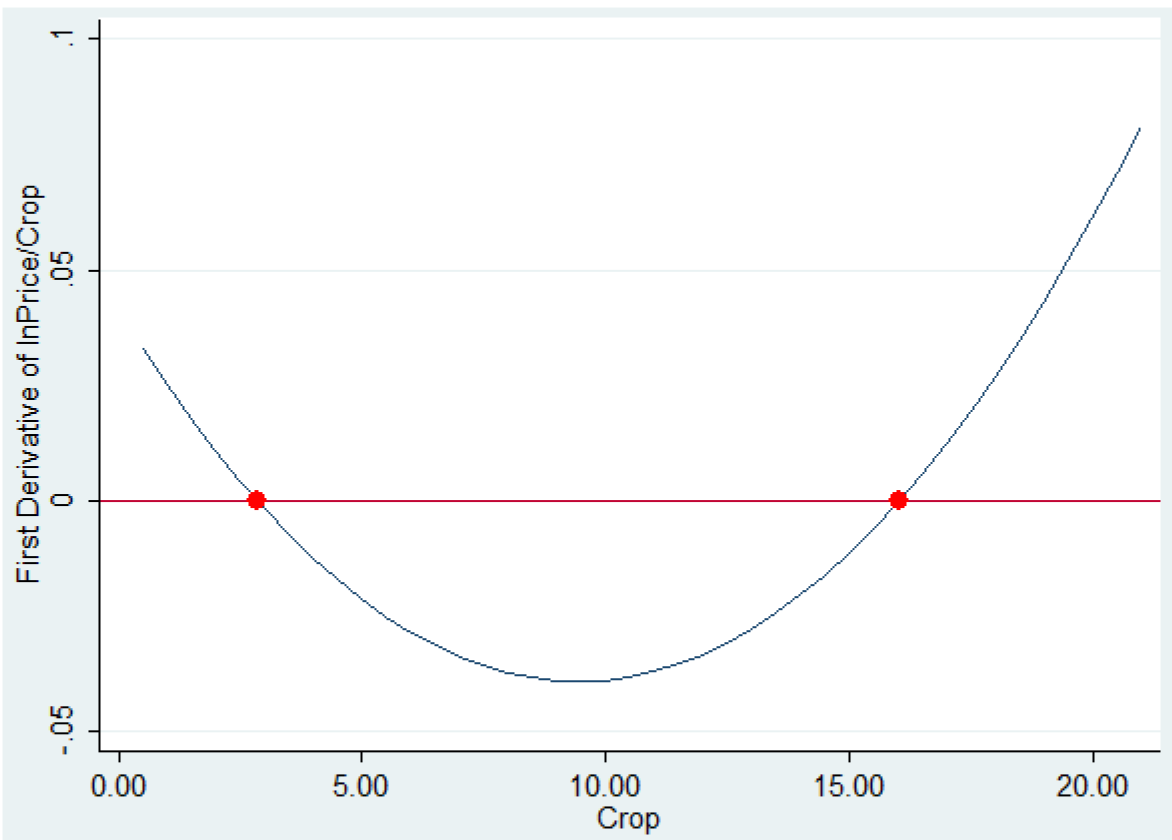


VII.2.3 Results of Hedonic Pricing Model with Including Both CROP and DAM_AGE

Model 1c includes both CROP and DAM_AGE as measures for maternal impact. First, a VIF test is conducted to ensure the model does not suffer from multicollinearity. We find that other attributes of price, not including CROP or DAM_AGE, are also highly significant as the previous two models. Once again, relationship between SIRE_AGE and price is significant and the results are nearly identical to those in Model 1a and Model 1b.

However, when including both maternal factors, the correlation between DAM_AGE and lnPrice becomes insignificant, while the cubic relationship between CROP and price remain significant. This likely occurs because even though both CROP and DAM_AGE are individually significant in predicting price, CROP is a better predictor of price when they are included in the same model. (Also, the adjusted R^2 of Model 1a is the highest). As in Model 1a, there is a positive relationship between 1^{st} -3^{rd} crop and price, with price reaching its peak at the 3^{rd} foal crop of foal, and then price decreases at the 4^{th} crop until the 17^{th} crop (Figure 7.4).

Figure 13: First Derivative of lnPrice with respect to CROP



VII.3 Results of Multivariate Regressions

Results of the multivariate regressions are present in Table 7.2.

Table 7.2: Results of the Multivariate Regressions

	Model 2a	Model 2b	Model 2c
Dependent Variable	LNEARN	LNEARN	LNEARN
Variables Name	Parameter Estimate (Std Error)	Parameter Estimate (Std Error)	Parameter Estimate (Std Error)
Book2	0.1466 (0.0884)	0.1471 (0.0884)	0.1466* (0.0884)
Book3	0.3207*** (0.0949)	0.3210*** (0.0949)	0.3204*** (0.0949)
Book4	0.5046*** (0.1009)	0.5065*** (0.1009)	0.5047*** (0.1009)
Book5	0.4319*** (0.1092)	0.4384*** (0.1092)	0.4343*** (0.1092)
Book6	0.4981*** (0.1177)	0.5062*** (0.1177)	0.5009*** (0.1177)
Book7	0.4801*** (0.1282)	0.4885*** (0.1282)	0.4837*** (0.1283)
Book8	0.3514** (0.1549)	0.3669** (0.1549)	0.3578** (0.1550)
DOB	-0.0518 (0.0409)	-0.0363 (0.0407)	-0.0473 (0.0410)
Filly	-0.1727*** (0.0400)	-0.1734*** (0.0400)	-0.1730*** (0.0400)
RNA	0.2508*** (0.0468)	0.2513*** (0.0468)	0.2514*** (0.0468)
lnPrice	0.4312*** (0.0172)	0.4319*** (0.0172)	0.4312*** (0.0172)
lnStudfee	-0.2105*** (0.0311)	-0.2164*** (0.0312)	-0.2137*** (0.0312)
DAMPROBT	0.0045 (0.0563)	-0.0114 (0.0554)	0.0110 (0.0565)
DAMBT	0.1060** (0.0436)	0.1484*** (0.0444)	0.1256*** (0.0459)
CROP	-0.0564*** (0.0078)	-	-0.0347** (0.0176)
DAM_AGE	-	-0.0434*** (0.0061)	-0.0190 (0.0138)
SIRE_AGE	-0.0249*** (0.0047)	-0.0246*** (0.0047)	-0.0248*** (0.0047)

Table 7.2 (continued): Results of the Multivariate Regressions

	Model 2a	Model 2b	Model 2c
Dependent Variable	LNEARN	LNEARN	LNEARN
Variables Name	Parameter Estimate (Std Error)	Parameter Estimate (Std Error)	Parameter Estimate (Std Error)
YEAR2007	0.2318*** (0.0637)	0.2555*** (0.0636)	0.2407*** (0.0640)
YEAR2008	0.2272*** (0.0640)	0.2506*** (0.0639)	0.2362*** (0.0644)
YEAR2009	0.4851*** (0.0654)	0.5087*** (0.0653)	0.4938*** (0.0657)
YEAR2010	0.6391*** (0.0675)	0.6627*** (0.0675)	0.6481*** (0.0679)
Intercept	7.0993*** (0.4015)	7.3198*** (0.4075)	7.2184*** (0.4107)
N	22734	22734	22734
Missing Values	3620	3620	3620
Adjusted R^2	0.0484	0.0483	0.0484
F Value	49.58	49.47	47.31
Prob > F	<.0001	<.0001	<.0001
Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.			

VII.3.1 Results of Multivariate Regressions with Including CROP

First, career race earnings are analyzed using only the variable CROP for the maternal effect. The results are reversed relative to those in the pricing model (Table 7.2).

Unlike the pricing model, a polynomial relationship between CROP and EARN is not discovered. Interestingly, there is a negative significant relationship between birthrank and race earnings, which suggest that the first foals from a mare earn more in their racing career on average, and as birthrank increase, earnings decrease on average. In addition, the relationship between SIRE_AGE and earnings is negative and significant, meaning that progeny by younger sires earn on average more on the racetrack. The variable lnPrice is included in the model, as it can represent some aspects of the yearling's quality. The sign is positive and significant at 1% level as expected, indicating that yearlings sold for higher prices at the Keeneland September Sale tend to have on average a higher future racing earnings.

The coefficients for Books (3-8) are positive and significant, while Book 2 is not significant. These results suggest that the yearlings sold later in the auction actually earn more on racetracks than the select yearling. One possible reason is that owners of racehorses with less notable pedigree tend to race the horses longer to generate more income from racing since such horses do not have as much breeding value. The coefficient for DOB is not significant in the earnings model, since the yearlings that were born later in the year will catch up physically to its counterparts quickly. The coefficient for FILLY is negative and significant. The reason for this is that there are smaller purses (the total amount of money paid out to the owners of racehorses at a race) for filly-restricted races. Also, a filly with a modest, but respectable race record, combined with a good pedigree often retires earlier to start breeding. Interestingly, the coefficient for RNA is positive. One possible reason is that horses whose hammer prices do not meet their reserve prices are undervalued by buyers; EARN, on average, is positively related to the year indicators. This might exist if purse sizes increase from year to year, so there is more money available to be won.

Surprisingly, stud fee is negatively correlated with racing earnings at the 1% level, which means as stud fee increases, career race earnings of the horse decreases. One possible explanation is that owners overrated the stallions in terms of stud fee, and high stud fee does not equal high sire quality in terms of racetrack performance. Further research should be conducted to investigate this result. The indicators of dam racing and producing performance are DAMBT and DAMPROBT. DAMPROBT is not a significant predictor of racing earnings, while DAMBT is positive and significant at the 5% level. This suggests that dam racing performance may be more influential on her progeny racing performance than her ability to produce previous black-type winners.

VII.3.2 Results of Multivariate Regressions with Including DAM_AGE

Second, the results from Model 2b, including dam age rather than foal birthrank, are presented. The effects of other attributes are robust to the change in specification. In addition, the relationship between SIRE_AGE and earnings is negative and significant, and the results are nearly identical to those in Model 2a. A negative and significant relationship between dam age and race earnings suggests as age of the foal's mother increases, race earnings of progeny decreases.

VII.3.3 Results of Multivariate Regressions with Including Both CROP and DAMGE

Finally, Model 2c presents the regression including both dam age and foal birthrank for predicting career earnings. Again, results for the effects of other attributes are robust to the change in specification. There is a negative significant relationship between foal birthrank and race earnings, suggesting that as birthrank increases, race earnings of progeny decreases on average. However, when both variables are included, dam age becomes insignificant. As in the pricing model, it appears that birthrank is more predictive of career earnings than age.

VII.4 Comparison of Marginal Effects

The marginal effects of the significant variables for Models 1a-1c and Models 2a-2c are presented in this section. Table 7.3 presents the comparison of marginal effects for Model 1a and Model 2a (models with the highest adjusted R^2), with all attributes except parental factors. Table 6 presents the marginal effects of CROP, DAM_AGE and SIRE_AGE.

Books, as we stated before, represent the sequence of selection. Results from the pricing model suggest that buyers are reluctant to pay more for yearlings presented in Book 2-8 than Book 1. However, marginal effects of Book 3-8 are positive on earnings, with the highest marginal effect of $44,231.00 from Book 6. In the pricing model, Year 2007 has a positive marginal effect of $14,895.31, while Year 2008-2010 have negative marginal effects on price due to the economic recession. However, marginal effects of year variables are all positive in the earnings model. Year 2007 still has a positive marginal effect of $16,975.53, whereas Year 2008-2010 also have positive marginal effects on average earnings than 2006, with the highest marginal effect of Year 2010 being $56,790.34. This result suggests a positive growing in purses of races.

Early born foals sell for an average of $6,944.42 more. Fillies sell for an average of $8,883.53 less, and earn $11,980.24 less on earnings. One explanation is that fillies with a moderate race record usually retire from racetracks earlier than colts in order to start their breeding career. RNA yearlings sell for $23,709.76 less on average, and earn almost $20,000 more on earnings. As stated in the previous results discussion, qualities of RNA yearlings may be underrated by Thoroughbred buyers. A dam who has produced black-type progeny places an average of $23,846.44 more on yearling's price, whereas a yearling by black-type dams sell for $7,439.20 more, and earn $6,732.02 more on average. When there is a $1,000 increase in sire stud fee, yearling hammer price will increase on average by $320, but career earnings will decrease on average by $330.

Table 7.3: Mean of Yearling Buyers' Marginal WTP for Price Attributes by Mare Age.

	Models Include CROP	
Attributes	Hedonic Pricing Model 1a	Earnings Model 2a
Book 2	-$33,315.74	-
Book 3	-$54,736.86	$24,240.16
Book 4	-$71,581.48	$43,016.25
Book 5	-$78,959.45	$36,408.25
Book 6	-$84,803.19	$44,231.00
Book 7	-$84,935.93	$42,324.82
Book 8	-$81,573.81	$28,145.87
YEAR 2007	$$14,895.31	$16,975.53
YEAR 2008	-$7,233.73	$16,802.08
YEAR 2009	-$40,227.43	$40,703.35
YEAR 2010	-$49,888.10	$56,790.34
DOB	$6 $6,944.42,944.42	-
FILLY	-$8,883.53	-$11,980.24
RNA	-$23,709.76	$18,641.49
DAMPROBT	$23,846.44	-
DAMBT	$7,439.20	$6,732.02
Stud Fee	$320/$1,000	-$330/ $1,000

A RESET test is constructed to test misspecification of independent variables, where cubic effects of the variables CROP, DAM_AGE and SIRE_AGE are discovered in the pricing functions. As the effects between the three variables and price are not linear, we select the maximum and minimum points shown in Figure 7.1-7.3 to illustrate the marginal effects. The marginal effects are given in Table 7.4. Results show that buyers are willing to pay on average $728.57 more for a 3rd crop foal than a 2nd crop foal in Model 1a (only including CROP), which increases on average to $890.47 as when effects of dam age are included. Buyers are willing to pay more for the progeny of mares age from 4-10, and the marginal effect is estimated to be $50.20 when dam age goes from 9 to 10 years old. The marginal effects of sire age on yearling prices are nearly identical in all three models. Results from Model 1a suggest when a sire age goes from 10-11, buyers' willingness-to-pay for the progeny decreases by $153.81, whereas when a sire age goes from 20-21, buyers are willing to pay $412.86 more for his progeny.

Table 7.4: Marginal Effects of Crop, Dam Age and Sire Age on Prices.

		LNPRICE		
Polynomial Variables	Selection	Models 1a (CROP)	Models 1b (DAM_AGE)	Models 1c (CROP, DAM_AGE)
Crop	Crop 2nd -3rd	$728.57	-	$890.47
	Crop 16th -17th	-$161.90	-	-32.38
Dam Age	Dam Age 9-10:	-	$50.20	-
	Dam Age 23-24	-	-$551.64	-
Sire Age	Sire Age 10-11	-$153.81	-$161.90	-$153.81
	Sire Age 20-21	$412.86	$291.43	$412.86

The marginal effects of CROP, DAM_AGE and SIRE_AGE on progeny race career earnings are shown in Table 7.5. CROP has a negative marginal effect on earnings in

Model 2a, suggesting that when foal birthrank goes up by one, there will be a decrease of $769.67 in earnings. When both foal birthrank and dam age are included in the function, dam age becomes insignificant; also a decreased marginal effect of CROP on earnings is observed. Dam age also has a negative marginal effect on progeny race earnings. Results from Model 2b suggests when dam age goes up by one, there will be a decrease of $256.31in earnings. Meanwhile the marginal effects of sire age on earnings are nearly identical in Model 2a-2c; there is a negative marginal effect of sire age on progeny race earnings.

Table 7.5: Marginal Effects of Crop, Dam Age and Sire Age on Earnings.

	LNEARN		
Polynomial Variables	Models 2a (CROP)	Models 2b (DAM_AGE)	Models 2c (CROP, DAM_AGE)
Crop	-$769.67	-	-$473.54
Dam Age	-	-$256.31	-
Sire Age	-$144.15	-$142.41	-$143.57

Chapter VIII: Discussion, Conclusion and Implications

At Thoroughbred auctions, yearling buyers make investment decisions based on experience and instincts. Anecdotally, breeders and buyers in the industry believe the first three crops of a mare are the best foals a mare produces. Based on this, we conducted a hedonic pricing analysis of yearlings sold at Keeneland September Sale from 2006 to 2010. The main objective of this paper is to identify Thoroughbred yearling buyers' preferences over parent age and progeny birthrank according to their behavior at public auctions, and then further investigate the relationships between those attributes and racing performance. Results from the pricing study suggested that buyers are willing to pay more on average for the 1st, 2nd and 3rd foal out of a mare. Results also show that buyers prefer progeny from younger mares; meanwhile, we find a significant negative correlation between dam age and progeny racing performance.

However, when including both attributes into one model, birthrank is more predictive of race earnings than dam age. Another interesting finding is the relationship between sire age and both price and progeny race earnings. In the hedonic pricing model, a polynomial effect of sire age is discovered, which suggests a reputational effect of the variable that buyers prefer progeny by sire age from 12 to 18 years. Meanwhile, there is a negative correlation with progeny race earnings and sire age. These results suggest that parent age and foal birthrank are significant in predicting racing performance.

We also test the attributes proven to be significantly correlated with hammer price in the multivariate regression of earnings. Surprisingly, many reverse correlations are discovered in the earnings regressions. The results suggest yearlings presented at the sale in Book 1 are sold at a higher price, which are referred as select yearlings, do not earn more than others on racetracks, on average. On the contrary, we find yearlings sold in later books earn more than the select ones. One possibility might be pedigree and conformation are overrated; yearlings with less impressive pedigree may race longer as they do not have as much breeding value.

Another surprising result is the impact of stud fee on earnings. Stud fee is used to represent the sire quality; more experienced sires with a good producing record usually have a higher stud fee. However, as stud fee increases, progeny earnings on racetracks decreases. Further research should be pursued to better understanding this result. One approach can be dividing sires into several groups according to stud fee. Perhaps differences in various categories of sires would help explain the result.

In addition, buyers are willing to pay more for the progeny out of dams that are black type horses, and it suggests in the earnings functions that it is positively correlated with the progeny future earnings on racetracks. However, whether a dam has produced a black-type progeny previously or not does not influence career performance of Thoroughbreds on racetracks. This is an interesting result as Thoroughbred buyers are willing to pay much more for a yearling that is half-brother/sister to a reputational racehorse.

Because of the high risks associated with the yearling business, and uncontrollable environmental factors that play vital roles in the Thoroughbred industry, it is almost impossible to predict a racehorse's performance on the racetrack.

Incorporating more explanatory variables in the model may help explain the percentage of the variance in earnings. For example, the distinct interactions of the dam and sire pedigree are believed to have a mixed impact on progeny quality; some Thoroughbred owners believe a good racehorse can be produced when mares are bred to the "right" sires, there are companies that provides mating ratings, i.e. TrueNick[9]. Further research would include mating ratings in the model to predict racehorse career earnings. Other factors such as days of training, daily nutrition intake, owners' characteristics or even horses' temperament indicators may also contribute to determine racehorses' career earnings.

The implication of this finding is useful for both breeders and stallion owners; sellers can adjust their reserve price accordingly to the age of sire, and stallion owners can refer the information to set a realistic stud fee. Racehorse owners can also benefit from this finding in making investment decisions. In the Thoroughbred industry, racing and breeding are two main sectors of the industry, which are connected to each other but are different in many ways. Understanding the preferences of Thoroughbred buyers is important for breeders to make profits from selling horses when it comes to make breeding decisions.

Appendix

1. Premium: An amount to be paid for certain feature of a product. For instance, insurance premium.

1. American Horse Council Foundation (AHCF): A trade organization in Washington, DC representing the horse industry serving as a unified voice for the horse industry.

2. The Jockey Club: The governing body for Thoroughbred breeding and racing.

3. PETA: People for the Ethical Treatment of Animals (PETA) is the largest animal rights organization in the world.

4. Ocala Breeders' Sales: Florida horse breeders' sales company.

5. Barretts: Established in 1989 to provide the breeding and racing industry in California.

6. Stakes race: A race for which an owner has to pay a fee or series of fees in order to run. Stake races included graded, listed, restricted and other black type races. There are three levels of graded stake races: Grade 1, 2 and 3 with Grade 1 referring to the best races. The minimum purse values for the American Graded Stakes are Grade 1, $300,000, Grade 2, $200,000, Grade 3, $100,000.

7. Pari-mutuel wagering system: A betting system in which all bets of a race are put together in a pool, and payoff odds are calculated by sharing the pool among all winning bets.

8. Handicap race: In handicap a race, horses carry different weights, better horses carry a heavier weight, to give him/her a disadvantage when racing against others)

9: TrueNicks: A company measure and rate the crosses from one male line with mares from other sire lines. TrueNicks estimates the quality of a potential breeding with a letter rating – A to D and F, with A^{++} to be the best.

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EDUCATION BACKGROUND

09/2014-Present	M.S. in Agricultural Economics
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09/2013-06/2014	Online education in Equine Management
	Kentucky Community and Technical College
09/2008-07/2013	B.S. in Veterinary Medicine
	Jilin University, China.
09/2009-06/2012	Minor Degree in Business Management
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PROFESSIONAL EXPERIENCE

01/2015-Present	***Research Assistant***
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03/03/2016	***Guest Lecturer***
	University of Kentucky, Agricultural Economics Department
08/2013-06/2014	***Intern***
	Darley America, Lexington, KY
01/2012-07/2013	***Research Assistant***
	Jilin University, Pharmacology lab, China

ACADEMIC CONFERENCE

2016	SAEA Annual Meeting San Antonio, TX

VOLUNTEER EXPERIENCE

10/2015	2015 Keeneland Breeders' Cup

HONORS AND AWARDS

2016	Spring International Student Scholarship, University of Kentucky
2009	Jilin University Scholarship, Jilin University, China
2011	Outstanding Student Cadre, Jilin University, China

OTHER RESEARCH PROJECTS

01/2015-05/2015	A Hedonic Price Analysis of Risk Preferences in Yearling Thoroughbred Buyers (Advisor: Jill Stowe, PhD)
01/2012-07/2013	Research on anti- inflammation effects of Chinese medicine. (Advisor: Xuming Deng, PhD)